ASSESSING LATRINE USE IN LOW-INCOME COUNTRIES: A FIELD STUDY IN RURAL INDIA

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Statement of Own Work

I, Antara Sinha, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

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Date: 15 September 2016

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Abstract

Sanitation programme monitoring is often limited to latrine access and coverage, with little emphasis on use of the facilities. This may be partially explained by the challenges associated with measuring individual and household latrine use. The conventional methods used each have their limitations.

The overall goal of this research was to improve the methods for assessing latrine use in low-income countries and enhance our understanding of the patterns and determinants of latrine use in rural India.

The evidence from a cross-sectional study to compare reported latrine use with a technology based measure, Passive Latrine Use Monitors, indicated that reported latrine use, though already suggesting low adoption, likely exaggerates the actual level of uptake of government constructed latrines in rural Odisha, India. Moderate agreement was obtained when comparing daily reported use during the previous 48 hours with the average daily PLUM count. Thus, if self-report measures are used, survey questions should focus on the 48 hours prior to the date of the survey rather than asking about "usual" latrine use behavior.

The study also assessed patterns and determinants of individual latrine use over 12 months in the study population. Based on a prior 48 hour recall measure of reported use, we classified use into three categories—"never", "sometimes" and "always/usually". We also assessed consistency of latrine use across the dry cold, dry hot and rainy seasons. Overall, we found that latrine use was poor. There was significant seasonal variation in use. There was increased reported likelihood of consistently using the latrine among females and where latrines had a door and roof. Older age groups and an increase in household size were associated with a decreased reported likelihood of consistently always/usually using the latrine versus never using it. The leading reported reason for non-use of latrines was a preference for open defecation.

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List of Abbreviations

1G PLUM	First Generation Passive Latrine Use Monitoring
2G PLUM	Second Generation Passive Latrine Use Monitoring
3G PLUM	Third Generation Passive Latrine Use Monitoring
APL	Above Poverty Line
BPL	Below Poverty Line
CCC	Concordance Correlation Coefficient
CLTS	Community-led Total Sanitation
CRT	Cluster Randomised Trial
DDWS	Department of Drinking Water and Sanitation
DHS	Demographic and Health Surveys
GoI	Government of India
GP	*Gram Panchayat*
GPS	Global Positioning System
GSM	Global System for Mobile Communication
HH	Household
ICC	Intra-class Correlation Coefficient
ID	Identification
IEC	Information, Education and Communication
IHHL	Individual Household Latrine
INR	Indian Rupee
ISHH	Intervention Surveillance Household
JMP	Joint Monitoring Programme
KAP	Knowledge, Attitudes, Practices
LSHTM	London School of Hygiene and Tropical Medicine
LUF	Latrine Use Frequency
MDGs	Millennium Development Goals
MICS	Multiple Indicator Cluster Surveys
MoDWS	Union Ministry of Drinking Water and Sanitation
NBA	*Nirmal Bharat Abhiya*n
NGO	Non-Governmental Organisation
NGP	*Nirmal Gram Puraskar*
NSSO	National Sample Survey Office
OD	Open Defecation
ODF	Open Defecation Free
OWG	Open Working Group on Sustainable Development Goals
PIR	Passive Infrared
PLUM	Passive Latrine Use Monitoring
PSU (USA)	Portland State University (United States of America)

SDA	Sustainable Development Agenda
SDGs	Sustainable Development Goals
SES	Socio-Economic Status
SQUAT survey	Sanitation, Quality, Use, Access and Trends survey
SS PLUM	SweetSense Passive Latrine Use Monitoring
SUMs	Stove Use Monitors
SWEETLab	Sanitation, Water, Environment and Energy Technologies Laboratory
TSC	Total Sanitation Campaign
UCB	University of California, Berkeley
UCB-TAMS	University of California, Berkeley Time-Activity Monitoring System
UK	United Kingdom
UN	United Nations
UNICEF	United Nations International Children's Emergency Fund
USAID	United States' Agency for International Development
VIP	Ventilated Improved Pit (latrine)
VWSC	Village Water and Sanitation Committee
WASH	Water, Sanitation and Hygiene
WB	World Bank
WHO	World Health Organization
WSP	Water and Sanitation Program
XIMB	Xavier Institute of Management Bhubaneswar

1 Thesis framework

This thesis describes research to evaluate methods for assessing latrine use in low-income countries and to describe patterns and determinants of latrine use among households that received latrines under the Government of India's Total Sanitation Campaign in rural India. This work was initiated in 2011 in the context of a cluster randomised controlled field trial (the 'Sanitation Trial') in rural Puri district, Odisha (India). Though there is evidence that latrine coverage is not translating into use, further research is required to improve the methods for assessing latrine use in low income countries and to enhance our understanding of the patterns and determinants of latrine use.

Chapters 1 – 3 of this thesis provide a context for the research. Chapter 2 is an introduction that provides the rationale for the research and background on the evolving definitions of sanitation, the issue of open defecation, international sanitation targets, monitoring mechanisms and challenges, the benefits of sanitation and finally an overview of the government's sanitation programme in India. Chapter 3 summarises the relevant literature on latrine access, coverage and use indicators in sanitation progress monitoring and measurement; the challenges in measuring latrine use; the determinants of use to understand why latrines are used or not used; and the association between latrine use and health outcomes.

Chapter 4 consists of the research aims and objectives. Chapter 5 describes the methods for developing and piloting of approaches for assessing latrine use. Chapter 6 describes the methods under which the final approaches were applied to assess latrine use in the context of a larger cluster randomised trial.

Chapters 7 and 8 include the study results in the form of two papers. Chapter 7 is a peer reviewed paper on a cross-sectional study published in July 2016 in the American Journal of Tropical Medicine and Hygiene, 95 (3), pages 720-727: *Assessing Latrine Use in Rural India: A Cross-Sectional Study Comparing Reported Use and Passive Latrine Use Monitors.* Chapter 8 is a paper that has been submitted for publication to International

Journal of Hygiene and Environmental Health in September 2016*: Assessing Patterns and Determinants of Latrine Use in Rural Settings: A Longitudinal Study in Odisha, India.* The introduction from the papers is sufficiently covered in this thesis. The reader may focus on the data analysis, results and discussion sections of these papers.

Chapter 9 is a concluding chapter that consists of a summary, implications of the research, reflections and way forward. The reflections in this chapter may be read as additional limitations to those already discussed in Chapters 7 and 8.

The appendix includes the main survey-based tool that was used in this research (Appendix 1). It includes three additional publications that I co-authored (Appendix 2-4). It also includes the instruction manual developed for the 3G PLUM by the University of California, Berkeley (Appendix 5).

Unless stated otherwise, I was responsible for all research covered by this thesis, with guidance from Thomas Clasen, Corey Nagel, Belen Torondel, Wolf P. Schmidt and Sophie Boisson. Throughout the thesis, use of the pronoun “we” refers to work that was conducted by the author, Antara Sinha, with guidance from her supervisors.

2 Introduction

2.1 Sanitation: Definition and scope

This section will unpack the different definitions of sanitation to appreciate its significance and scope.

Sanitation may be defined broadly as the safe disposal of human excreta (WHO-UNICEF, 2014c). However, such a broad definition tends to mask the large and complex system of inter-related factors that it encompasses. Over the years, the definition of sanitation has been refined so that it may comprehensively reflect the "system" that it truly represents.

The original definition of sanitation, according to the Millennium Development Goals (MDG) was: "access to facilities that hygienically separate human excreta from human, animal and insect contact. Facilities such as sewers or septic tanks, pour-flush latrines and simple pit or ventilated improved pit latrines are assumed to be adequate, provided that they are not public." (UN, 2003)

By 2005, the MDG Task Force on Water and Sanitation adopted the following working definition of "basic sanitation": "the lowest cost option for securing sustainable access to safe, hygienic and convenient facilities for excreta and sullage disposal that provide privacy and dignity while ensuring a clean and healthful living environment both at home and in the neighbourhood of users."(Lenton et al., 2005)

In 2010, the United Nations recognised the right to safe (and clean drinking water and) sanitation as a human right and defined it as: "access to, *and use of*, excreta and wastewater facilities and services that ensure privacy and dignity, ensuring a clean and healthy living environment for all"(WHO-UNICEF, 2015). These facilities and services must be safe, physically accessible, affordable and culturally acceptable (COHRE et al., 2008).

The post-2015 agenda focused on Sustainable Development Goals builds further on this by seeking to achieve “progressive realisation” of the Human Right to Water and Sanitation by extending access to the “unserved”, “moving people up the service ladder” and “progressively eliminating inequalities in access”(WHO-UNICEF, October 2015).

Thus, it may be derived that an adequate sanitation system, which meets current definitions, has wide implications that extend beyond health to include social, cultural and economic benefits. Furthermore, it also implies that while sanitation facilities may exist at a household level (as recommended by the MDGs), sanitation is an environmental issue that requires consistent use by each household and universal use by all (Craven, 2012).

2.2 Global sanitation targets and coverage rates, and progress monitoring

This section will address the issue of open defecation, the sanitation targets set by the United Nations (UN) with reference to the MDGs, the progress made at a global and regional level against the MDG targets, and monitoring progress on sanitation as per the Joint Monitoring Programme (JMP) of the World Health Organization (WHO) and the United Nations International Children’s Emergency Fund (UNICEF).

Sanitation is considered to be fundamental to “human health and survival” (WHO, 2014b). Yet many people, especially those in low-resource settings, have no access to sanitation. Latest estimates indicate that globally, 2.4 billion people still use unimproved sanitation facilities, such as hanging latrines, bucket latrines, pit latrines without a slab, with 40 percent living in Southern Asia (WHO-UNICEF, 2015). As many as 946 million defecate in the open (WHO-UNICEF, 2015), behind bushes, into open bodies of water and street gutters, resulting in both transmission of disease and environmental contamination (WHO, 2014a).

2.2.1 The issue of open defecation: global and regional trends (1990-2015)

The United Nations call to action on sanitation included the elimination of open defecation (OD) by 2025 (UN, March 2013). The urgency to address this issue stems from the fact that "open defecation constitutes a health and human capital crisis" (Coffey et al., 2014) with far-reaching implications that "keep(s) women under the threat of harassment, violence and rape. It forces girls to abandon education at puberty. It contributes to a cost of $260bn a year through death, ill health and loss of productivity." (Excerpt from United Nations Deputy Secretary-General Jan Eliasson's address at the campaign launch to end open defecation, May 28, 2014).

Globally, open defection rates have declined from 24% in 1990 to 13% in 2015 (WHO-UNICEF, 2015). It has also been estimated that sixteen countries have reduced open defecation rates by at least 25 percentage points during the MDG period, with India recording a steep decline of 31% (Figure 2-1) (WHO-UNICEF, 2015). However, a previous JMP estimate on "unfinished business" of the MDGs may offer some perspective on these gains. It suggested that until 2014, India was home to 597 million people practicing open defecation, making it the country with the highest number of open defecators globally (Figure 2-2) (WHO-UNICEF, 2014a).

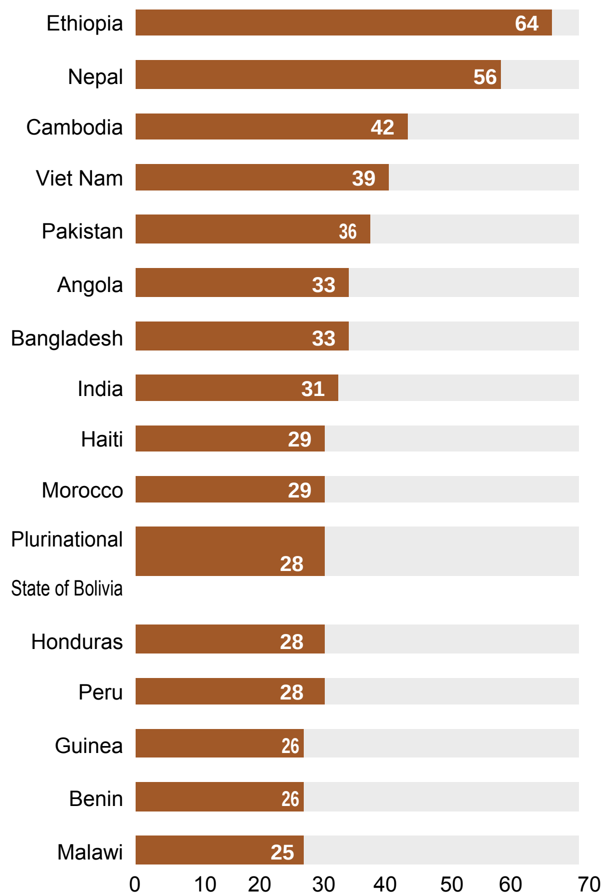

Figure 2-1: Reduction in the proportion of population practicing open defecation, from 1990 to 2015 (%). Sixteen countries have reduced open defecation rates by at least 25% (WHO-UNICEF, 2015)

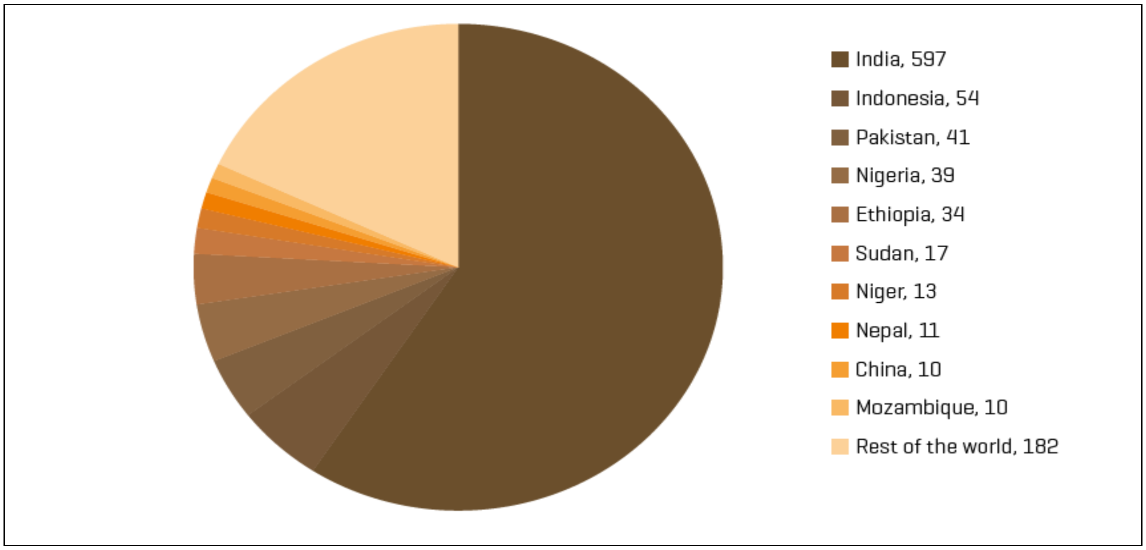

Figure 2-2: Top 10 countries with the highest numbers of people (in millions) practicing open defecation (WHO-UNICEF, 2014a)

Further review of the data reveals that similar to global trends (Figure 2-3), open defecation in India too remains a largely rural phenomenon (GoI, 2011, Planning Commission, 2013, WHO-UNICEF, 2015). While estimates of rural India indicate a drop in those practicing open defecation from 91% in 1990 to 61% in 2015 (WHO-UNICEF, 2015), it does not feature among countries making adequate progress in reducing the problem (WHO-UNICEF, 2014a).

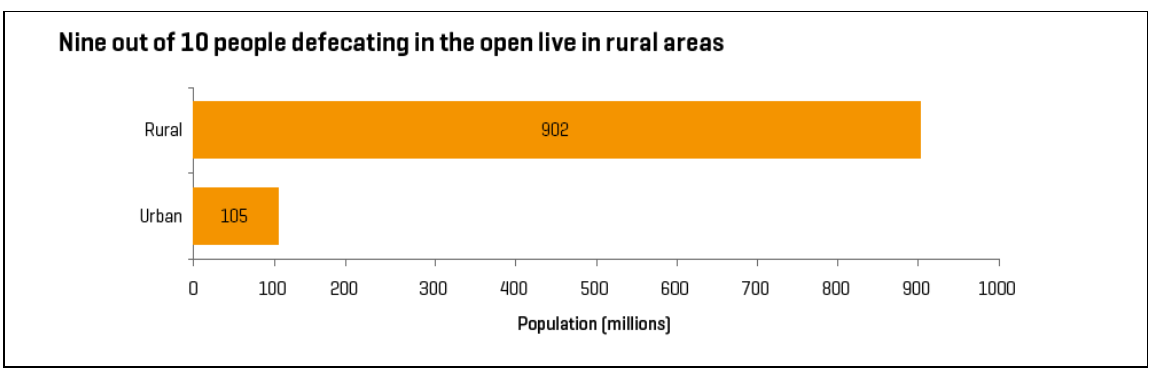

Figure 2-3: Population practicing open defecation in rural and urban areas, 2012 (WHO-UNICEF, 2014a). This estimate remained unchanged in the 2015 update (WHO-UNICEF, 2015).

2.2.2 The Millennium Development Goals sanitation target

The United Nations global anti-poverty targets, collectively referred to as the MDGs, had a specific target 7C that included sanitation. It aimed to halve the proportion of population without sustainable *access* to “basic sanitation” between 1990 and 2015(WHO-UNICEF, 2014a). It is notable that the term “basic”’ sanitation is now the new terminology used in the post-2015 goals and is occasionally used interchangeably with “improved” sanitation. (UN, 2015, WHO-UNICEF, October 2015).

The WHO/UNICEF JMP is the institutionalised mechanism for assessing progress toward the MDG sanitation target. For this purpose, it counted individuals with “access to improved sanitation facilities”, defined as a facility that “hygienically separates human excreta from human contact”(WHO-UNICEF, 2014c)and “ensure(s) that excreta do not re-enter the immediate household environment” (WHO-UNICEF, 2014b). It included flush or pour-flush latrines connected to a pit, piped sewer or a septic system, simple pit latrines with slab, and ventilated improved pit latrine or composting toilet. It excluded public or shared latrines, open pit latrines, bucket latrines or open defecation (WHO-UNICEF, 2014c). Table 2-1 below includes the exact definitions of both “improved” and un-improved” sanitation facilities as followed by the JMP (WHO-UNICEF, 2014c).

Table 2-1: Improved and un-improved sanitation facilities – JMP definitions (WHO-UNICEF, 2014c)

Improved sanitation	
Flush toilet	Uses a cistern or holding tank for flushing water, and a water seal (which is a U-shaped pipe below the seat or squatting pan) that prevents the passage of flies and odours. A pour flush toilet uses a water seal, but unlike a flush toilet, a pour flush toilet uses water poured by hand for flushing (no cistern is used).
Piped sewer system	Is a system of sewer pipes, also called sewerage, that is designed to collect human excreta (faeces and urine) and wastewater and remove them from the household environment. Sewerage systems consist of facilities for collection, pumping, treating and disposing of human excreta and wastewater.
Septic tank	Is an excreta collection device consisting of a water-tight settling tank, which is normally located underground, away from the house or toilet. The treated effluent of a septic tank usually seeps into the ground through a leaching pit. It can also be discharged into a sewerage system.
Flush/Pour flush to pit latrine	Refers to a system that flushes excreta to a hole in the ground or leaching pit (protected, covered).
Ventilated improved pit latrine (VIP)	Is a dry pit latrine ventilated by a pipe that extends above the latrine roof. The open end of the vent pipe is covered with gauze mesh or fly-proof netting and the inside of the superstructure is kept dark.
Pit latrine with slab	Is a dry pit latrine whereby the pit is fully covered by a slab or platform that is fitted either with a squatting hole or seat. The platform should be solid and can be made of any type of material (concrete, logs with earth or mud, cement, etc.) as long as it adequately covers the pit without exposing the pit content other than through the squatting hole or seat.
Composting toilet	Is a dry toilet into which carbon-rich material (vegetable wastes, straw, grass, sawdust, ash) are added to the excreta and special conditions maintained to produce inoffensive compost. A composting latrine may or may not have a urine separation device.
Special case	A response of "flush/pour flush to unknown place/not sure/DK where" is taken to indicate that the household sanitation facility is improved, as respondents might not know if their toilet is connected to a sewer or septic tank.
Unimproved sanitation	
Flush/pour flush to elsewhere	Refers to excreta being deposited in or nearby the household environment (not into a pit, septic tank, or sewer). Excreta may be flushed to the street, yard/plot, open sewer, a ditch, a drainage way or other location.
Pit latrine without slab	Uses a hole in the ground for excreta collection and does not have a squatting slab, platform or seat. An open pit is a rudimentary hole.
Bucket	Refers to the use of a bucket or other container for the retention of faeces (and sometimes urine and anal cleaning material), which are periodically removed for treatment, disposal, or use as fertilizer.
Hanging toilet or hanging latrine	Is a toilet built over the sea, a river, or other body of water, into which excreta drops directly.
No facilities or bush or field	Includes defecation in the bush or field or ditch; excreta deposited on the ground and covered with a layer of earth (cat method); excreta wrapped and thrown into garbage; and defecation into surface water (drainage channel, beach, river, stream or sea).

In an effort to improve monitoring of access to sanitation, since 2008 the JMP used a four rung sanitation ladder (Figure 2-4) to enable a dis-aggregated analysis of trends beyond the dichotomous "improved" and "un-improved" sanitation categories (WHO-UNICEF, 2015). It offered a more nuanced appreciation of the proportion of population with no sanitation facilities at all, those using "unimproved" technologies, those relying on shared but otherwise acceptable facilities, and those using "improved" technologies (WHO-UNICEF, 2014c). It thereby allowed countries to assess where they were making progress even if they were not meeting the absolute criteria required by the MDG targets (WHO-UNICEF, 2009).

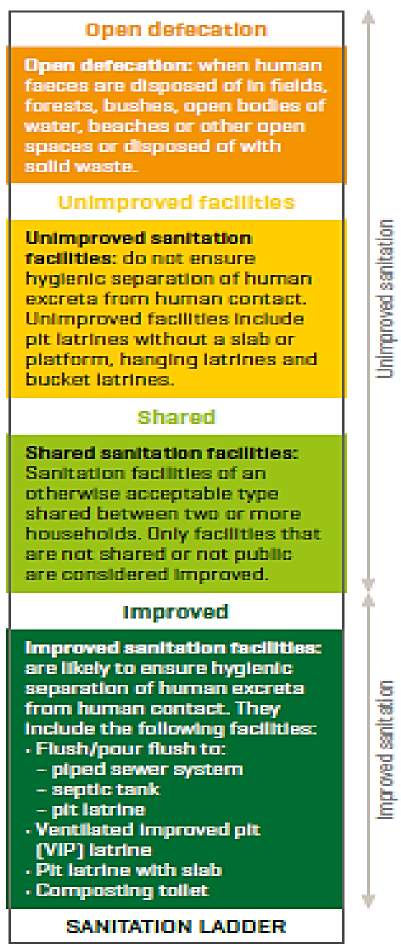

Figure 2-4: The sanitation ladder - WHO-UNICEF Joint Monitoring Programme (WHO-UNICEF, 2014c)

2.2.3 Global and regional sanitation coverage and trends

Worldwide sanitation coverage rates have increased with 68% of the population using improved sanitation facilities in 2015 compared to 54% in 1990 (WHO-UNICEF, 2015). However, progress is far short of the MDG sanitation target of 77%. In 2015, there were still an estimated 47 countries, areas or territories (Figure 2-5) where less than half the population used an improved sanitation facility (WHO-UNICEF, 2015).

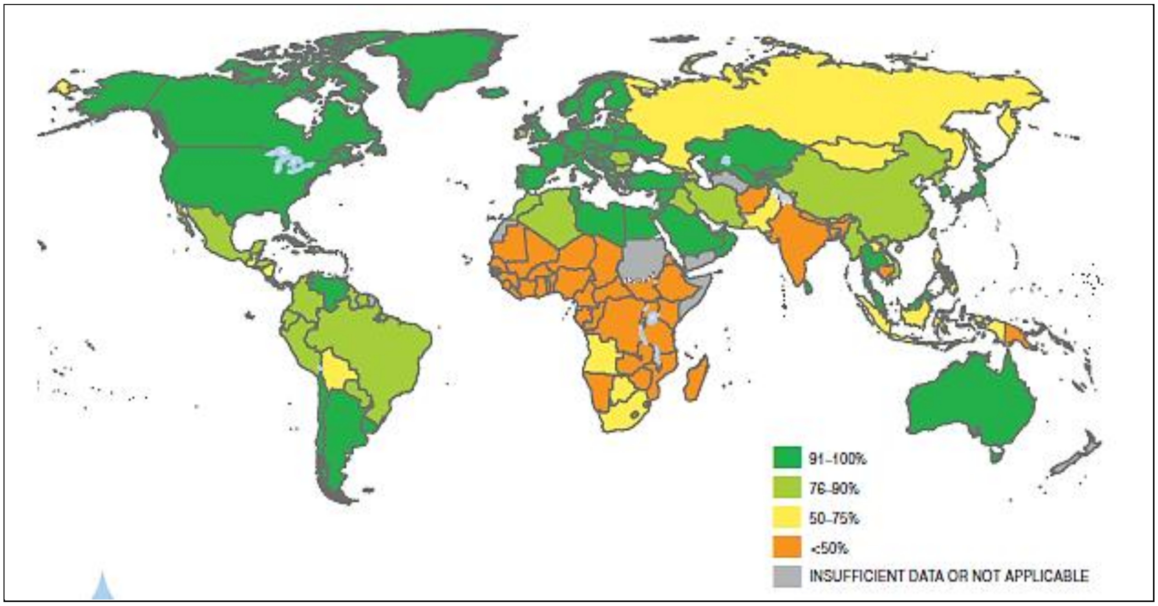

Figure 2-5: Proportion of population using improved sanitation facilities in 2015 (WHO-UNICEF, 2015)

At a regional level, Southern Asia and sub-Saharan Africa continue to have among the lowest levels of coverage (Figure 2-6). By 2015, 28% of the population in India had gained access to improved sanitation since 1990 (WHO-UNICEF, 2015). However, the estimates also reveal that among the 1001 million people without access to such facilities in Southern Asia, the greatest number (792 million) are still in India (WHO-UNICEF, 2014a). Thus, despite "moderate progress", India, along with 68 other countries in the world, was not on track to meet the MDG target in 2012 (Figure 2-7) (WHO-UNICEF, 2014a, WHO-UNICEF, 2015). These trends indicated that the world would miss the 2015 MDG sanitation target by almost 700 million people (WHO-UNICEF, 2015).

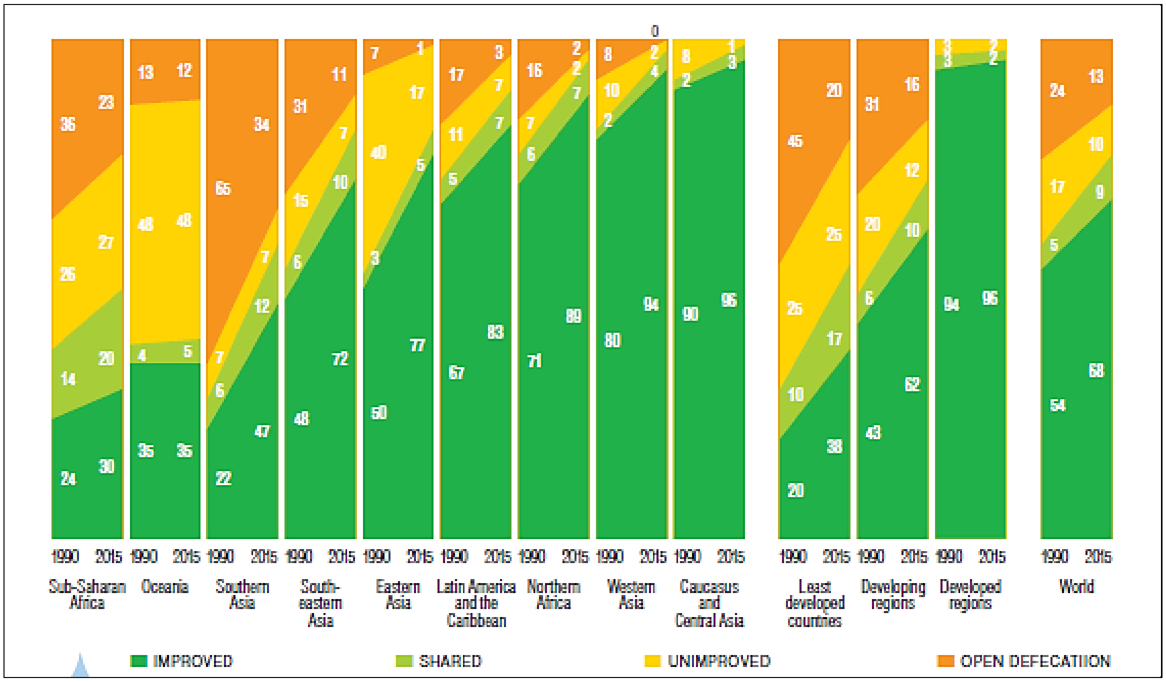

Figure 2-6: Sanitation coverage trends (%) by MDG regions, 1990-2015 (WHO-UNICEF, 2015)

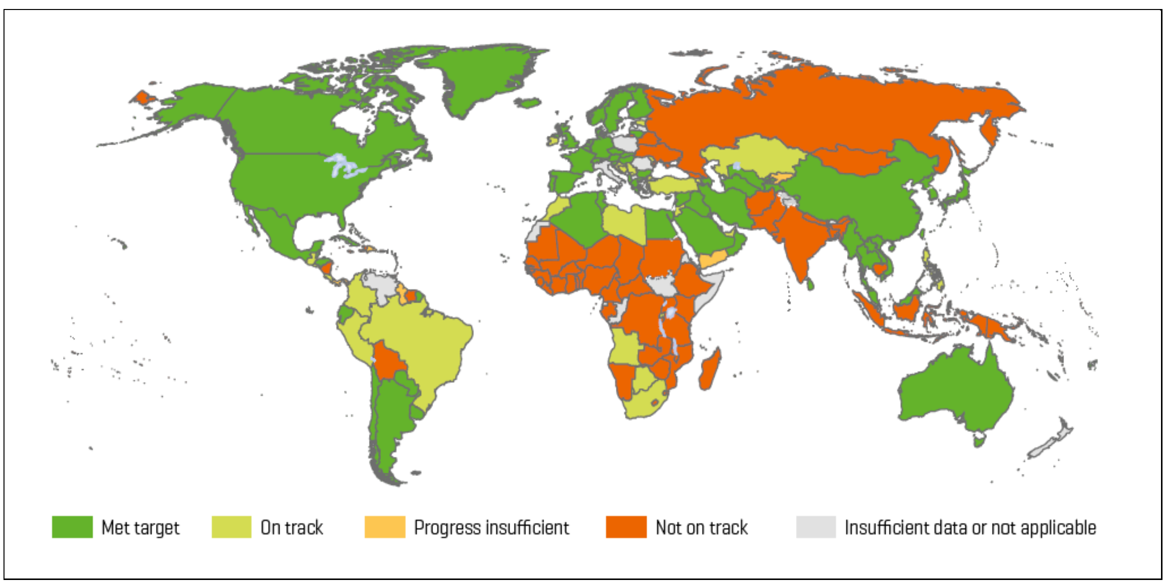

Figure 2-7: Progress towards the MDG sanitation target, 2012 – 69 countries were not on track (WHO-UNICEF, 2014a)

With the end of the MDG period in 2015, the UN developed a set of successor objectives that it designated “Sustainable Development Goals” (SDGs). Of the 17 SDGs proposed by the Open Working Group on Sustainable Development Goals (OWG) of the UN, Goal 6 seeks to “ensure availability and sustainable management of water and sanitation for all” (OWG, 2014). It comprises six technical targets which extend beyond drinking water, sanitation and hygiene (WASH) and address wastewater management, water efficiency, integrated water resource management, and protection of ecosystems (WHO-UNICEF, 2015). These were developed by global WASH stakeholders and facilitated by the JMP, to “build on the MDGs and address ‘unfinished business’ as a first priority” (WHO-UNICEF, 2014b), including the deficit in meeting the sanitation target. Target 6.2 applies specifically to sanitation:

> “By 2030, achieve access to adequate and equitable sanitation and hygiene for all, and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations.”

With a view to seeking the “progressive realisation of universal access to WASH” during the post-2015 era, experts have identified key elements to be addressed in the targets, including: elimination of open defecation; universal access to WASH; hygiene, with priority to hand washing and menstrual hygiene management; eliminating inequalities; improving service levels; going beyond the household to target other settings, such as schools and health facilities; and addressing sustainability of services (WHO-UNICEF, October 2015, Cronk et al., 2015).

Further details on WASH post-2015 are included in Section 2.2.4, with a focus on aspects that are germane to this research.

2.2.4 Monitoring progress on sanitation: from access to use of sanitation facilities

Monitoring progress on sanitation is critical as it provides the required evidence base for a variety of interventions and actions (Cotton and Bartram, 2008, Bartram et al., 2014). This became especially important in the case of the MDGs that were internationally regarded as “strong drivers of change and development” (Cotton and Bartram, 2008). The JMP was tasked with the responsibility of monitoring progress towards MDG target 7C and providing estimates that are comparable among countries and across time (WHO-UNICEF, 2015). This section will focus on the JMP monitoring mechanism with reference to the MDG sanitation target. While an in-depth discussion of the subject is beyond the remit of this thesis, an attempt will be made to highlight some monitoring issues that explain the context sufficiently and have a direct bearing on the research.

Sanitation monitoring by the UN began in the 1960s, when the WHO worked in co-ordination with national governments to gather data and monitor the status and progress of the global sanitation sector (Bartram et al., 2014). Since then the sector has witnessed considerable changes (Figure 2-8): targets have been modified, definitions have been refined, the purposes of monitoring have been more clearly di-lineated, nature and quality of data sources and related methodologies have been made more transparent, and a collaborative framework with national governments the world over has been established to further streamline the process and minimise conflicting results (Cotton and Bartram, 2008, Bartram et al., 2014).

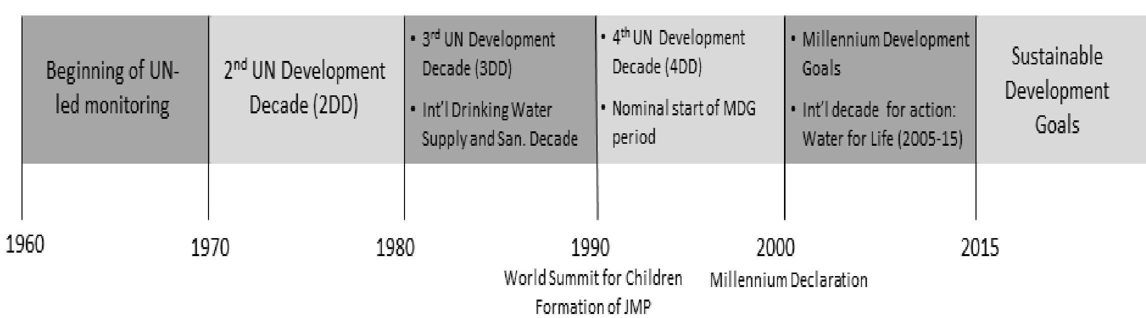

Figure 2-8: Timeline of international targets and actions related to drinking water and sanitation (Bartram et al., 2014)

The table below (Table 2-2) briefly traces key changes in sanitation monitoring by the WHO and JMP in the past few decades.

Table 2-2: Changes in global sanitation monitoring undertaken by the WHO and JMP. Adapted from: (WHO and UNICEF, 2006,COHRE et al., 2008, Cotton and Bartram, 2008, Craven, 2012, Bartram et al., 2014)

Time period		**Target**	**Approach**	**Challenges**	**Outcomes**
1981-1990	"International Drinking-water Supply and Sanitation Decade"	"Substantial improvement in drinking water and sanitation by 1990".	Data sources: national water and sanitation agencies, Ministries of health. Lengthy questionnaires dealing with coverage and institutional issues.	Varying and often incomplete definitions used by countries. Inaccuracies in coverage reporting: for e.g., government supplied latrines were counted even when dysfunctional or unused and privately constructed latrines were not counted. Estimates varied considerably between reporting years. Reliance on supply-side/ government data with little scope for independent verification.	National action plans for drinking water supply and sanitation developed. Increased emphasis on community participation in management of water and sanitation facilities. Shift from supply-side/ government data to user-side/ household data. Household surveys conducted by international agencies, for e.g., UNICEF.
Post-1990	Millennium Development Goals and the JMP	Part of the MDGs, which were first presented in 2001. The drinking water and sanitation target was adopted in its final form in	In 1990, WHO and UNICEF combined monitoring efforts into a "Joint Monitoring Programme for Water Supply and Sanitation". In 1997, WHO and UNICEF decided on a change in strategy for estimating coverage, switching from government provided data to	In practice, reporting only of the number of households with access to an "improved" facility, defined as one that "hygienically removes excreta from human contact" (Lenton et al., 2005). Challenging to measure social factors such as privacy and dignity, for the sector globally	In 2006, WHO and UNICEF published "Core Questions on Drinking Water and Sanitation for Household Surveys". This was done to encourage wide use of a harmonised set of survey questions in all important household surveys from which the JMP gathers its data so that results may be more easily compared.

		2006 as Target 7c: to halve, between 1990 and 2015, "the proportion of the population without sustainable access to safe drinking water and basic sanitation".	data collected through censuses and nationally representative household surveys (for e.g. UNICEF's Multiple Indicator Cluster Surveys (MICS) and the United States' Agency for International Development's (USAID) Demographic and Health Surveys (DHS). A working definition of "basic sanitation" was developed: "the lowest cost option for securing sustainable access to safe, hygienic and convenient facilities for excreta and sullage disposal that provide privacy and dignity while ensuring a clean and healthful living environment both at home and in the neighbourhood of users."(Lenton et al., 2005) "Sanitation ladder" used for monitoring purposes by means of grouping into "rungs" based on the type of technology (refer to Figure 2-4). Thus, monitoring done by counting	without introducing subjectivity. Differences in questions used in household surveys at international and national levels preventing comparability of results.	The relevant questions on latrine use are: Q6. "What kind of facilities do members of your household usually use?" Q7. "Do you share this facility with other households?" Q8. "How many households use this toilet facility?" Q9. "The last time (name of child under 3 years of age) passed stools, what was done to dispose of the stools?" Thus, households with private access to an improved sanitation facility that was not dysfunctional or unused was included in the 'access' statistic. The WHO-UNICEF survey specified the need for further research to determine if shared sanitation facilities should be considered un-improved, or whether there is a reasonable cut-off point within which sharing may be considered hygienically acceptable.

			individuals with "access to an improved sanitation facility" at a household level. Coverage levels of sanitation facilities were determined by the type of technology. For monitoring purposes, the following definition was adopted: "an improved sanitation facility is one that hygienically separates human excreta from human contact. Sanitation facilities that are shared with other households are not considered to be improved".		
2010	Sanitation declared to be a human right.		Clarified the parameters by which adequacy of sanitation was to be evaluated. Defined as "access to, and use of, excreta and wastewater facilities and services that ensure privacy and dignity, ensuring a clean and healthy living environment for all." These facilities and services must be safe, physically accessible, affordable and	Complex and nuanced definition that requires multiple socio-cultural indicators to be considered to enable an objective and comprehensive evaluation.	JMP introduced: Wealth quintile analysis (JMP reports 2004, 2010, 2012, 2014). Analysis of urban-rural disparities. Evaluating the rate of progress achievable in the context of "progressive realisation".

			culturally acceptable. Requirement of appropriate analytical approaches to measure equality and identify discrimination.		

With the emergence of WASH post-2015, the JMP has recognised the requirement for refining definitions and potential indicators for global monitoring of progress in this area. An Inter-Agency Expert Group on SDG monitoring has been established by the UN for the development of measurable targets and technically robust indicators. The approach has been to specify a normative interpretation for each of the core concepts contained in the SDG WASH targets; identify a clearly definable, measurable indicator that yields data that corresponds to the normative interpretation; and to describe the method of data collection (WHO-UNICEF, October 2015). The JMP also plans to expand its existing sanitation "ladder" so that the various service rungs may adequately monitor "the progressive realisation of universal access in all countries at different stages of development" (WHO-UNICEF, October 2015). The aspects regarding access to and use of sanitation in the household have been highlighted in the context of the service ladder (WHO-UNICEF, October 2015):

First, the lowest rung of the service ladder corresponds to "no service/ open defecation". The normative definition remains practically unchanged from the MDG period. The indicators include a) the percentage of the population practising open defecation (defecating in bushes, fields, open water bodies or other open spaces), b) the percentage of children under five whose stools are hygienically disposed of. The data sources for this are household surveys and the implementation timeline is immediate.

Second, the next lowest rung includes "unimproved" sanitation. The monitoring indicator for this is the percentage of the population using a sanitation facility that does not hygienically separate human excreta from human contact or is shared with other households. The data source for this service level is also household surveys with an immediate implementation timeline.

The third lowest rung is "shared" sanitation. The monitoring indicator for this is the percentage of population using an improved sanitation facility shared with other households. The data will be collected through household surveys and it may be implemented immediately. The shared status of a facility is considered important because shared facilities may be less hygienic than facilities used by a single household and may discourage use (WHO-UNICEF, 2006), especially by women and children (SIWI, 2003). It has also been suggested that shared facilities raise concerns from a human rights perspective about lack of privacy and a risk of violence (WHO-UNICEF, October 2015).

The fourth rung from the bottom refers to “basic” sanitation. The normative definition of this too remains largely unchanged from the MDG period. The indicators include a) the percentage of population using an improved sanitation facility, not shared among two or more households, b) the percentage of households in which the improved sanitation facility is used by all members of the household (including men and women, boys and girls, elderly, people with disabilities) whenever needed. While the data source for the first indicator is household surveys, which may be implemented immediately, the implementation timeline for the second indicator is short term. Additionally, there appears to be no further explanation regarding the measurement of this aspect.

The top two rungs of the ladder include “safely-managed” and “sustainable” sanitation services. While the indicators for these levels have been specified, the data sources are wider, including household surveys, administrative, population and environmental data and are likely to be more complex relative to the previous indicators. The timelines for implementation are expectedly medium-long term.

Thus, while the SDGs refer to “use” and “use by all” of sanitation facilities, the lack of further guidance on how to measure this aspect remains a challenge in sanitation monitoring.

2.3 Benefits of improving sanitation

This section will briefly address the benefits of sanitation as it will be discussed in greater detail in the literature review, especially with regard to latrine use and its impact on health.

2.3.1 Sanitation and health

At least since Chadwick's seminal "Report on an inquiry into the sanitary condition of the labouring population in Great Britain" in 1842 (Chadwick, 1842) and John Snow's investigations into the cholera epidemic in 19th century London (Snow, 1855), sanitation has been widely perceived as basically a health intervention (Cairncross et al., 2013). In 1990, the estimated global disease burden (limited to diarrhoeal and selected parasitic diseases) from un-improved water and sanitation was 6.8% of all disability-adjusted life years (DALYs) (Prüss et al., 2002). A more recent estimate in 2010 only attributes 0.9% of global DALYs to the same risk factor, resulting in a fall in rank between 1990 and 2010 (Lim et al., 2013). However, in the opinion of some experts, these 2010 figures may be questionable owing to methodological issues (Watts and Cairncross, 2012, Schmidt, 2014) , thereby re-iterating the need to go beyond "the numbers game" while evaluating the merits, health or otherwise, of water, sanitation and hygiene interventions. In fact, as a re-affirmation of the importance of WASH for the prevention of diarrhoeal disease burden in low- and middle-income settings, recent estimates indicate that in 2012 a total of 842,000 diarrhoea deaths were estimated to be caused by inadequate WASH as a cluster of risk factors. It amounted to 1.5% of the total disease burden and 58% of diarrhoeal diseases. Of these total deaths, 280,000 were estimated to be caused by inadequate sanitation specifically. The number of preventable deaths in children under five was estimated to be 361,000, representing 5.5% of deaths in that age group (Prüss-Ustün et al., 2014).

Though lacking epidemiological rigour (Clasen et al., 2010, Schmidt, 2014), there is a substantial body of research that suggests that poor sanitation is associated with important risks to health, including infectious diarrhoea (Barreto et al., 2007, Genser et al., 2008, Green et al., 2009, Fink et al., 2011, Wolf et al., 2014). Diarrhoea is the second leading cause of morbidity and mortality in children under the age of five worldwide (UNICEF-WHO, 2009, Liu et al., 2014). In India, diarrhoea alone caused the deaths of

212,000 children under five years in 2010, accounting for 12.6% of child deaths (Liu et al., 2012). Pathogens excreted in human and animal faeces are known to cause diarrhoea and are transmitted mainly through the faecal-oral route (Leclerc et al., 2002), as illustrated below (Figure 2-7) in an adaptation of Wagner and Lanoix's "F-diagram"(Cairncross et al., 2013). Sanitation, along with water and hygiene, serves as a primary barrier in breaking the transmission chain by reducing exposure to disease causing agents (Emerson et al., 2001, Bloomfield, 2012). Further, sanitation interventions are likely to be effective when they are not only limited to provision and use by adults but also facilitate safe disposal of infants' faeces (Lanata et al., 1998).

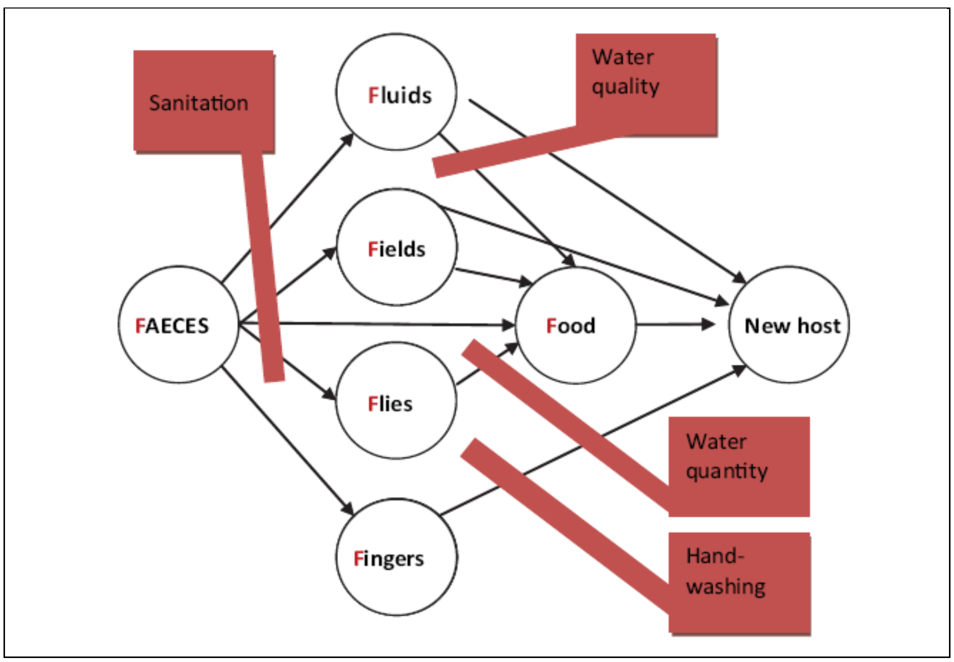

Figure 2-9: F-diagram showing routes for faecal-oral transmission (adapted from Wagner & Lanoix, 1958)

However, some research also suggests that the health impact of (water and) sanitation extends beyond diarrhoea alone. Many other neglected tropical diseases, such as trachoma (Emerson et al., 2004, Stocks et al., 2014), soil-transmitted helminthiasis (Albonico et al., 2006, Ziegelbauer et al., 2012, Strunz et al., 2014) , schistosomiasis (Grimes et al., 2014) also have faecal-oral transmission pathways and improved sanitation may be essential for any long-term control and elimination efforts (Mara et al., 2010). Moreover, research has pointed towards a plausible link, albeit not direct, between sanitation and acute respiratory infections (Schmidt et al., 2009, Mara et al., 2010). There is also increasing attention to the role of poor water, sanitation, hygiene in childhood under-nutrition, mediated by diarrhoea and nematode infections (WB, 2008); increased gut permeability and nutrient mal-absorption (Humphrey, 2009); stunting (Spears, 2012, Spears et al., 2013); and early life cognitive development and immunity (Prüss-Üstün and Corvalán, 2006).

2.3.2 Wider benefits of sanitation

As mentioned in Section 2.1, the United Nations recognises "the right to safe and clean drinking water and sanitation as a human right that is essential for the full enjoyment of life and all human rights" (UN, 2010). It may therefore be posited that sanitation is about much more than health. Some research has suggested that social and cultural factors, such as safety and security, comfort, convenience, privacy and prestige, far outweigh health considerations in motivating households to adopt and use toilets (Jenkins and Curtis, 2005, Jenkins and Scott, 2007). Furthermore, the gender-related benefits of safe sanitation are also significant (Pearson and Mcphedran, 2008, Routray et al., 2015). For women, access to household sanitation reduces the risk of sexual violence when travelling to and from public facilities and open fields (Lennon, 2011, Massey, 2011, Biswas, 2014), and for girls, access to improved sanitation facilities at school has been found to improve attendance and reduce drop-outs (Mahon and Fernandes, 2010).

The economic benefits of improved sanitation include reduced health sector costs, fewer days lost due to illness at work, school or in taking care of an ill family member, and convenience time gained due to closer proximity of toilets, less waiting time at shared facilities or walking to open defecation sites (Hutton et al., 2007, Hutton and

Bartram, 2008, Hutton, 2015). A study by the World Bank's Water and Sanitation Program (WSP) estimated the total annual economic impact of inadequate sanitation in India in 2006 to be USD 53.8 billion a year - the equivalent of 6.4% of India's gross domestic product in the same year (WSP, 2011b). In contrast, most African countries were only in the range of 1% to 2% (Chambers and Von Medeazza, 2013).The health-related economic impact in India was estimated at USD 38.5 billion and accounted for the largest category of impacts. It was followed by access time (productive time lost to access sanitation facilities or open defecation sites) at USD 10.7 billion (WSP, 2011b).

2.4 Government of India sanitation programmes

2.4.1 The Total Sanitation Campaign: India

This section provides an overview of the Total Sanitation Campaign (TSC) in India, which was operational at the time that this study was conducted. It provided the policy and implementation guidelines according to which the sanitation intervention (detailed description available in Section 6.1) was rolled out at the study site in rural Odisha.

The Census of India estimated that the percentage of rural households that had access to a latrine (the ratio of the number of rural households with improved sanitation facilities to the total number of rural households, expressed as a percentage) increased from 21.9% in 2001 to 30.7% in 2011 (GoI, 2011) (refer to Figure 2-10 for a comparison of the percentage share of households with no latrine facilities in India in 2001 and 2011).

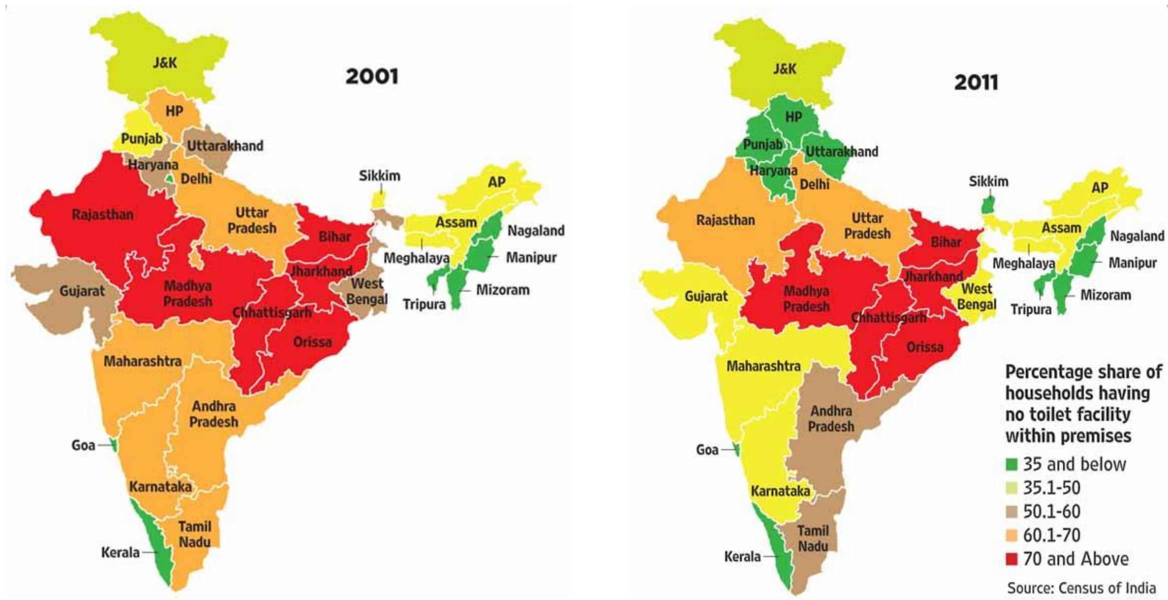

Figure 2-10: State-wise percentage share of households with no latrine facilities in India in 2001 and 2011 as per Census of India (GoI, 2011)

However, even within the Indian government, different agencies have come up with varying figures: for example, the National Sample Survey Office (NSSO) conducted the 69th round of the survey between July– December 2012 and found that 40.6% rural households had access to a latrine facility. Further, only 38.8% of these households had access to an "improved source of latrine". Among Indian states, Odisha fared among the worst, with only an estimated 18.7% rural households having access to a latrine (National Sample Survey Office, December 2013). The Union Ministry of Drinking Water and Sanitation (MoDWS), Government of India, had put the figure at 68% in 2010, suggesting that approximately 493 million people in rural India had access to sanitation facilities (Department of Drinking Water and Sanitation: Ministry of Rural Development, April 2011). However, the MoDWS subsequently downward revised the figure estimating that only 40.35% rural households had access to latrines based on findings from a Baseline Survey conducted by the State Sanitation Departments (under the directive of the M0DWS) in 2012-2013 (MoDWS, 22 August 2014).

The variations in these estimates triggered political controversy and debate, raising concerns about more than 35 million “missing toilets” at the household level (Sengupta, 21 October 2013, Jitendra et al., 16-31 January 2014). Several potential explanations, including methodological and time differences (MoDWS, 22 August 2014), among others, were cited by the relevant agencies to account for the discrepancies. Regardless, the collective evidence undisputedly points to one fact: India’s current rural sanitation status remains poor despite substantial public spending, on-going policy interventions and re-iterated political resolve spanning approximately three decades (Sengupta, 21 October 2013). Considerable progress needs to be made for the country to achieve open defecation free status and meet the targets set by the United Nations (WHO-UNICEF, 2015).

In response to the rural sanitation challenge, the Government of India (GoI) launched the TSC in 1999. Moving beyond the 2015 MDG target, this comprehensive programme aimed to accelerate sanitation coverage in rural areas and make India open defecation free (‘*Nirmal Bharat’*) by 2017, largely through the construction and use of individual household pit latrines (DDWS, 2011, GoI). The actual construction of toilets under the TSC began only in 2001 (WSP, 2011a). The TSC was designed as a “demand-driven, community-led”, “low to no subsidy” approach to total sanitation and was implemented by the state governments (DDWS, 2011). It was a departure from India’s earlier Central Rural Sanitation Programme, which was launched in 1986 as a supply-driven, high subsidy and infrastructure oriented latrine construction programme that ultimately met with little success (Planning Commission, 2013). The TSC was allegedly informed by learning that:

- Gains in latrine coverage do not translate into latrine uptake or use (WSP, 2011a).
- Motivating behaviour change through inter-personal communication in order to end open defecation is critical (Chakraborty, 1998).

- Subsidies are not a key motivational factor. People are willing to spend money to construct latrines as they value the convenience and privacy that it offers (Mitra, 1998).
- Safe sanitation is a 'public good' that needs to be adopted at a community-wide level for health outcomes to be achieved (WSP, 2011a).

The TSC emphasised "basic low cost" latrines covering all rural households. An ex-post incentive of Indian Rupees (INR) 2200[1], which was subsequently raised to INR 3200 – 3700, was offered to Below Poverty Line (BPL) beneficiaries for construction of one unit of an individual household latrine if the household took responsibility for the construction (with guidance) and also used the same (DDWS, 2011). Relatively better off "Above Poverty Line (APL)" households were not eligible to receive the financial incentive but were motivated to undertake latrine construction independently (DDWS, 2011). Recognising the challenges in creating awareness and demand for construction and use of sanitation facilities in rural settings, the campaign was also designed to have a sustained information, education and communication component to drive the effort (DDWS, 2011, Planning Commission, 2013).

The TSC received further impetus in October 2003 when the Indian government announced the "*Nirmal Gram Puraskar*" (NGP), or the Clean Village Prize, as a fiscal incentive to villages achieving "open defecation free" (ODF) status through full sanitation coverage in households and schools (DDWS, 2011). The (NGP) award gained in popularity, spurring much greater community ownership of the campaign and resulting in (relatively greater) rural sanitation gains (Alok, 2010, Planning Commission, 2013). A recent evaluation of the TSC conducted by the Government of India helped in identifying key issues and limitations of the programme (Planning Commission, 2013). This also paved the way for further reform.

[1]A subsidy of INR 2200 was provided to BPL households when the TSC/ WaterAid programme was first rolled out in Odisha. The amount was raised by the Government to INR 3200 mid-programme.

2.4.2 Moving beyond the TSC: *Nirmal Bharat Abhiyan* (NBA) and *Swachh Bharat* Mission

While the prevailing programmatic guidelines at the time of the research described in this thesis were those of the TSC, it is important to briefly address the successive changes made to the national sanitation programme by the Government of India between 2012 and 2014. This has been included primarily to enhance the understanding of the reader and minimise confusion, if any, because of an apparent overlap of timelines with the study.

In 2012 the TSC metamorphosed into the *Nirmal Baharat Abhiyan* (NBA), which aimed to increase rural sanitation coverage so that 50% of *gram panchayats* (groups of villages headed by the Village Council) attain "*Nirmal Gram"* (Clean Village) status by 2017 and "*Nirmal Bharat"* (Open Defecation Free or Clean India) by 2022. Among other modifications, the NBA increased the incentive/subsidy to construct a latrine in eligible households to INR 10,000. It also widened the eligibility criteria of households to include certain marginalised, dis-advantaged and low income APL families (Ministry of Drinking Water and Sanitation, 2013).

By the middle of 2014, the country saw a change in government at the centre and with it re-invigorated political support at the highest levels to address the sanitation challenge in India, including a pledge from the Prime Minister himself that India should build "toilets before temples" (Jitendra, 5 October 2013). The NBA has now been renamed "*Swachh Bharat"* Mission (Clean India) in which the Prime Minister has demanded urgent action and advanced the target year for achieving universal sanitation coverage from 2022 to 2019 (MoDWS, 22 August 2014, Kumar, 2014). According to the Ministry of Drinking Water and Sanitation (GoI), notable, among other changes, is the strategic shift from the NBA's emphasis on building toilets to effectively triggering behaviour change in the population to accept the need to build and, most importantly, use toilets in a sustained manner (MoDWS, 22 August 2014).

2.5 Summary

Despite decades of effort, sanitation remains an under-performing sector globally; many countries, including India, are lagging on this front. The world has not met its MDG 2015 target as a result.

Sanitation serves as a key mechanism to hygienically dispose of excreta and acts as a primary barrier in breaking the faecal-oral transmission chain by reducing exposure to disease causing agents. However, its benefits are not limited to only health but also extend to social, gender and economic gains, to mention just a few.

Over time, international agencies have refined the definition of (basic/improved) sanitation to encompass the socio-cultural and rights based dimensions as well. The term "access" to sanitation facilities is central to these definitions and yet, in practice, it is often found to imply *coverage*, rather than *use.* Further, while there is token mention of use of sanitation facilities by all, whenever needed, in the recently developed SDG WASH indicators, there is inadequate explanation as to how this is likely to be monitored and measured.

The Indian government's sanitation programmes have also undergone changes in the past few decades. They have morphed from supply and high-subsidy oriented programmes to demand driven, community-led, low- to no-subsidy programmes. However, regardless of the favourable change in approach, progress monitoring has tended to remain linked to coverage instead of use. This results in infra-structure creation or building of toilets, with inadequate emphasis on (consistent and sustained) latrine use.

Given the poor state of the sanitation sector in India, there is reason to believe that the emphasis on improving access to sanitation facilities by building more latrines may not always be translating into latrine use. Furthermore, effective monitoring and measurement of latrine use is required so that progress may be monitored more accurately and comprehensively.

As Chapter 3 will demonstrate, existing research reveals a gap in understanding of latrine use behaviour, the potential tools that may be employed to reliably measure use, and whether and under what circumstances improved sanitation reduces adverse exposure and improves health.

3 Literature review

3.1 Introduction

This review further examines the literature on 1) the emphasis on latrine access and coverage and the relative neglect of latrine use indicators in sanitation progress monitoring and measurement in the context of the Indian government's Total Sanitation Campaign and other countries; 2) the challenges in measuring latrine use; 3) the evidence on determinants of use to provide insight into why latrines are used or not used; and 4) the association between latrine use and health outcomes.

This review concludes the following:

- Latrine use is an important outcome indicator in monitoring sanitation programmes. An emphasis on latrine access alone, an output indicator, without addressing latrine use, is not likely to yield desired programmatic outcomes, including open defecation free status and health and other gains from sanitation.
- Measuring individual and household latrine use is challenging. The conventional methods used each have their limitations. Certain technology based measures may address critical concerns arising from some of the other methods by increasing objectivity, allowing real time monitoring to assess adherence, and offering an extended perspective of latrine use.
- Latrine use behaviour is not determined exclusively by access to latrine facilities. It is influenced by several determinants, including socio-cultural, economic, education and income levels, water availability and structural factors, among others.
- Latrine use, especially if practiced by all at both household and community levels, may potentially result in health gains.

3.2 The issues of latrine access, coverage and use indicators in sanitation monitoring and measurement

Sanitation monitoring plays an instrumental role in assessing sanitation status, understanding key issues, informing policy, focusing development efforts and stimulating investment in the sector (Bartram et al., 2014). It has different purposes for a range of interventions and actions that may be implemented at global, national or local levels (Lenton et al., 2005,Cotton and Bartram, 2008, Bartram et al., 2014). It has been suggested that “you get what you measure” and that “delivery mechanisms have a tendency to adapt themselves to deliver what is being measured” (Wicken, 2008). This section examines literature on the trend in the sanitation sector to rely on the “output” indicators of “access to improved infrastructure” and “coverage” (Wicken, 2008) as sufficient proxy measures for sanitary status and progress, with an inadequate emphasis on “outcome” indicators, including (consistent and sustained) latrine usage (Planning Commission, 2013, Hutton, 2015) and zero excreta areas (Wicken, 2008).

3.2.1 Reviewing the Indian Total Sanitation Campaign

By 2016, the Central Indian government’s sanitation programmes have already been operational for three decades (Planning Commission, 2013). Yet globally, India remains the country with the highest number of open defecators, with the majority living in rural areas (WHO-UNICEF, 2014a, Coffey et al., 2014). While there may be differences in recent estimates of the percentage of open defecators in rural India (WHO-UNICEF, 2014a), the highest estimate has emerged from a GoI study that 72.63% households in rural India spread over 27 sample states practice open defecation regardless of whether or not they have access to latrines (Planning Commission, 2013). This estimate may be considered significant for three reasons. Firstly, the persisting scale of the problem reflects the relatively low development priority accorded to the sector (WSP, 2011a, Ghosh and Cairncross, 2014). Secondly, it offers insights into likely reasons for open defecation, even among households that have latrines, including that it is “an established age old practice” with little or no stigma attached to it (Department of

Drinking Water and Sanitation: Ministry of Rural Development, April 2011, Planning Commission, 2013, Coffey et al., 2014, Ghosh and Cairncross, 2014), and generally low awareness of improved hygiene behaviour (Banerjee and Mandal, 2011, Planning Commission, 2013). Thirdly, and most importantly, it reveals that latrine access does not always translate into use (Sanan and Moulik, 2007, WSP, 2011a, National Sample Survey Office, December 2013, Garn et al., 2016), thereby also hindering health and other gains reaped from sanitation. From a monitoring perspective, it implies that the focus should also be on latrine use rather than only on access and coverage, although a robust indicator for the same is not yet readily available for integration into large-scale household surveys (Bartram et al., 2014, Coffey and Spears, 2014, Cotton and Bartram, 2008).

3.2.1.1 Issues emerging from reliance on latrine access and coverage figures

There are four important issues that arise from existing reliance on latrine coverage as a measure of sanitation.

Firstly, national performance aggregates on latrine access and coverage may mask disparities between and within different regions, states, districts and populations even though a common national rural sanitation programme is being implemented (WSP, 2013, Ghosh and Cairncross, 2014, WHO-UNICEF, 2015). For example, according to the Indian Census 2011, one in three rural households had access to a latrine – an increase from one in five in 2001 (GoI, 2011). It would appear that the country has made considerable progress. However, in reality some Indian states lag significantly behind others with latrine coverage ranging from 90% to 22% across States (Ghosh and Cairncross, 2014). For instance, recent research that used data from Census 2001 and 2011 for the 20 most populous states in India, points out wide inter-regional disparities where the proportion of households with access to individual household latrine (IHHL) facilities is highest in the States in the North-Eastern region at 69.4% and lowest in the

Eastern region at 35.9%(Ghosh and Cairncross, 2014). Furthermore, within the Eastern region, for example, disparities between States are also marked with IHHL coverage as high as 70.1% in the Andaman and Nicobar Islands and as low as 22% in Jharkhand and Odisha. A dis-aggregated analysis at the district level within each State points to disparities between districts. Districts in the 20 states were divided into six categories according to their rates of progress, ranging from "very slow (0-10%)" to "excellent (>50%)", where % values indicated coverage rates. In Odisha, for example, of a total of 30 districts, the progress between 2001 and 2011 in 27 districts was found to be "very slow (0-10%)" and in the remaining three, it was found to be "slow (10-20%)" (Ghosh and Cairncross, 2014). Moreover, findings from a World Bank study that evaluated the performance of the Total Sanitation Campaign over one decade (WSP, 2011a) suggest that the prioritisation of the poorest rural households (as classified by the GoI as "Below Poverty Line" or BPL households) over other households (classified as "Above Poverty Line" or APL) also appeared to vary between states. Overall BPL and APL coverage at a national level were estimated to be 59% and 48% against their targets respectively, indicating that greater priority had been accorded to BPL households in alignment with the TSC guidelines. However, there were instances of too wide a disparity as well. For example, in Odisha, the reported difference in latrine coverage between these two populations was even greater, with BPL and APL coverage estimated at 46% and 20% against their targets respectively (WSP, 2011a). This may point to strategic limitations in the government's sanitation programme where low APL achievement may prevent it from ultimately achieving its goal of universal rural sanitation (Planning Commission, 2013).

Secondly, latrine access and coverage figures may vary considerably often resulting in an inconsistent view on performance (Cotton and Bartram, 2008, Bartram et al., 2014). As discussed in Section 2.4.1, different government agencies within the government of India have given widely different estimates of latrine coverage figures in households in rural India between 2010 and end 2012 (GoI, 2011, Department of Drinking Water and

Sanitation: Ministry of Rural Development, April 2011, National Sample Survey Office, December 2013, MoDWS, 22 August 2014). This suggests that regardless of the justifications made to account for these discrepancies, which range from differences in perspective, differences in the nature and source of data used or variations in definitions (Cotton and Bartram, 2008, Bartram et al., 2014), the actors in the sanitation sector will have to choose from varying estimates on which to base future planning/ target setting, actions, interventions and policies. This may lead to incoherence and non-alignment in what is envisaged as a common national rural sanitation programme.

Thirdly, coverage figures may also be exaggerated: the JMP had estimated that in order to achieve the 2015 MDG target for sanitation, overall sanitation coverage in India should be 57% and rural sanitation coverage should be 52% (UNICEF, September 2006). In 2010, the Department of Drinking Water and Sanitation, GoI, estimated the rural sanitation coverage figure at 68% (Department of Drinking Water and Sanitation: Ministry of Rural Development, April 2011), which suggested that India may have already met its corresponding MDG target. While this was subsequently downward revised by the same Ministry to 40.35% in 2012-13 (MoDWS, 22 August 2014), it implies that reported coverage figures may be exaggerated. Similarly, others have argued that water target claims are also exaggerated (Clasen, 2012). Thus, excessive reliance on such figures for monitoring purposes may not be productive.

Lastly, the emphasis on latrine coverage and access indicators has skewed the availability of data in favour of coverage of individual household latrines at both national and state levels, with insufficient reported data on the use of latrines that have been constructed (Ganguly, 2008). Additionally, while the focus on households as the primary unit of assessment has been logical in the context of the MDG Target 7C, the post-2015 agenda also includes users in non-household settings (Cronk et al., 2015). Thus, future monitoring and reporting mechanisms will also need to address these concerns.

3.2.1.2 Latrine use: a neglected evaluation indicator in sanitation programmes

The Indian government's routine monitoring system for the rural sanitation sector, the aim of which is an open defecation free (ODF) India, involves periodic tracking of inputs (budget spent) and outputs (latrines constructed). It does not typically track usage of toilets (Ganguly, 2008, WSP, 2013), the 69th National Sample Survey (National Sample Survey Office, December 2013) being an exception. Outcomes such as ODF communities are monitored to a limited extent through the NGP verification process but latrine use data is not available in the public domain and there is little effort to track sustainability in NGP-winning local governments (WSP, 2013). As a result, implementers are incentivised to prioritise latrine construction over use or sustainable behaviour change (Wicken, 2008, WSP, 2013). The consequence, according to some experts, is that the programme has been reduced to "a no-gain toilet construction scheme….where India built millions of toilets but people (did) not use them" (Jitendra et al., 16-31 January 2014).

The inadequate emphasis on latrine use in the context of the TSC and the fact that some current implementation practices do not always adhere to TSC guidelines has been highlighted in certain reports/ studies.

According to a 2008 review by WaterAid of the TSC in 5 states, a qualifying criterion for a "*Nirmal Gram Puraskar"* (NGP or Clean Village Prize, which is a GoI fiscal incentive programme for local governments) application is supposed to be an ODF and fully sanitised village. However, 100% latrine coverage was considered to be a sufficient proxy measure for NGP applications at the district level (WaterAid, 2008). This may be because it is simpler to deliver and count hardware than measure behaviour (Clasen et al., 2012b). It may also be partly due to the numerical nature of sanitation targets (Wicken, 2008).

A few WSP-supported rural sanitation sector assessments conducted by Indian state governments between 1997 and 2004 revealed the following:

a) An assessment carried out by the Government of Andhra Pradesh in 2004 on its state-wide rural sanitation programme showed that considerable funds were spent to construct 2.95 million household latrines post-2001. While this resulted in substantial increase in coverage, a random concurrent evaluation showed that approximately 50% of these subsidised latrines remained unused or were used for other purposes (Sanan and Moulik, 2007).
b) A government evaluation undertaken in Maharashtra estimated that while 1.6 million subsidised latrines had been built between 1997 and 2000, only about 47% were being used (Sanan and Moulik, 2007).
c) A random evaluation in Himachal Pradesh in 2003 showed 30% or less usage of approximately 0.3 million latrines that were built through a subsidy-driven programme in the 1990s (Sanan and Moulik, 2007).

The evidence from these assessments suggests that the sanitation programmes in India, the TSC included, have had a focus on providing latrines, often on a subsidised basis, rather than motivating usage. As a result most people continue to defecate in the open, not because they lack access to latrines, but because they do not feel compelled to change their behaviour (Sanan and Moulik, 2007). Thus, the outcomes of hardware driven programmes, such as the TSC, tend to be poor.

A sample survey conducted by TARU/UNICEF in ODF/NGP villages revealed that only 81% households had access to IHHLs, of which only 64% reported using them.It was also found that 6% reported use of community or shared toilets while approximately 30% practiced open defecation (TARU, 2008). In principle, ODF or “zero excreta” jurisdictions is a good outcome indicator of a sanitation programme that takes into account latrine access, use, maintenance, hygiene behavior, completeness of coverage and equity (Wicken, 2008, Craven, 2012). It is anticipated that the results are also likely to be more sustainable than traditional hardware-oriented programmes as greater community engagement and action leads to improved use and maintenance of the facilities (Chambers, 2009). However, the TARU report suggests that in practice the NGP scheme may not be as effective as predicted because of concerns regarding the incentive programme's verification process (WSP, 2011a, WSP, 2013); the inadequate focus in the TSC on the use of latrines and hygiene promotion through intensive social mobilisation efforts; and as mentioned above, the numerical nature of sanitation targets (Wicken, 2008).

A joint assessment of a decade of the TSC by the Water and Sanitation Program, the World Bank, and the Ministry of Rural Development, GoI, in 2011, revealed that monitoring of latrine usage emerged as one of the weakest aspects of the overall monitoring system. In a sample of 22 districts across 21 states that were studied, it was found that latrine use was monitored by only one-third of the sample districts, of which approximately half reported doing so on an ad-hoc basis rather than routinely. Furthermore, sustained monitoring of NGP/ ODF villages was reported by less than one-third of the sample districts, providing little or no information on the sustained ODF status of the village (WSP, 2011a).

The WSP conducted a study on linking service delivery processes and outcomes in rural sanitation by sampling 56 districts across 12 states in India in 2011 (WSP, 2013). It also drew on the dataset and findings of a MDWS, GoI, study on NGP impact and sustainability (2010) that used the same sample. Service delivery processes were defined as the steps adopted by the district governments to achieve sanitation outcomes in the TSC. A total of nine processes were further grouped into three thematic components, namely "catalysing, implementing and sustaining, depending on the stage of the service delivery cycle to which they correspond(ed)". Outcomes were defined as the "usage of toilets by rural households" estimated at a district level by the number of persons using a latrine and the number of children under three whose faeces were disposed safely to the total population surveyed, expressed as a percentage. The findings showed that sample districts scored highest on processes in the catalysing component, followed by implementing and sustaining, implying that it is down-stream programme service delivery and sustainability that require improvement. Among the identified nine processes, districts scored lowest on rewards and recognition, followed only by monitoring. Figure 3-1 presents district scores on quality of individual processes in each component wherein green signifies an area of strength, and yellow and red represent areas requiring further improvement and the weakest processes, respectively. District ratings on the three thematic components were all significantly correlated with district-level usage outcomes (Pearson's r values of 0.642 for catalysing; 0.503 for implementing and 0.667 for sustaining, all significant at $p < 0.01$). Overall, it was found that the adoption of higher quality of processes by a district increases the likelihood of sustained usage and behaviour change in NGP populations (WSP, 2013).

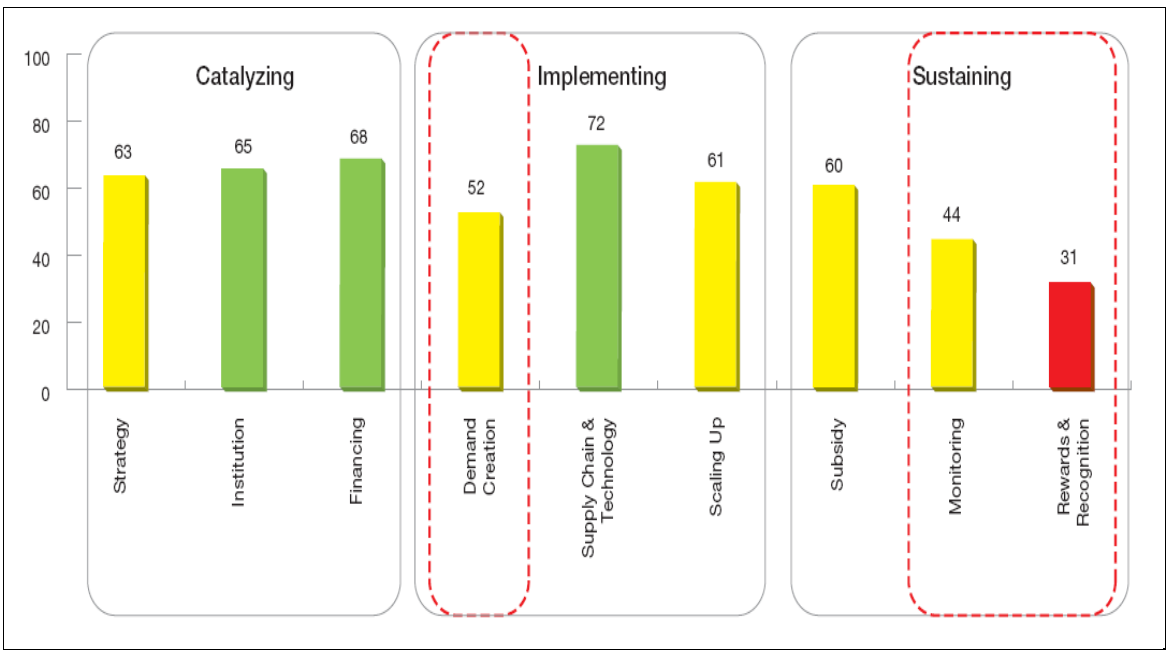

Figure 3-1: District scores on individual service delivery processes (grouped thematically) in the Indian TSC. The colour coding implies the following: green denotes a score of 65 or more, yellow a score of 32 or more and red is 31 or less than 31 (N=56 districts) (WSP, 2013)

This study is important for the following reasons: a) It demonstrates the significance of latrine use as an outcome indicator that, especially when used in conjunction with "zero excreta jurisdictions", can provide valuable programmatic insights and a course for corrective action; b) it offers further evidence to show that in the TSC demand creation for sanitation tends to be limited to toilet construction rather than motivating behaviour change and sustained use of latrines; c) it corroborates the findings from the WSP 2011 TSC evaluation study that identified TSC programme monitoring as an area of weakness.

An independent evaluation of the TSC to assess the socio-economic impact of the programme was conducted by the Planning Commission, GoI, in 2013 (Planning Commission, 2013). The study sampled 11,519 beneficiary households in 122 districts from 27 Indian states. The outcome variable was "reduction in open defecation" and the output variable was measured in terms of construction of latrine facilities at the household level due to the TSC. A household was considered to be practising open defecation if "at least one member of the family defecates in the open". Based on this definition, it was estimated that even 12 years after the launch of the TSC, 72.63% of rural India still defecates in the open. The study also found that the outcome of most information, education and communication (IEC) activities was limited to the construction of household latrines without being able to create demand for latrines and encourage use. In this context, it was found that 46% *Gram Panchayats* (GPs or local Village Councils) had appointed motivators but a majority of these motivators were doing little beyond persuading people to construct latrines. It may be important to point out that demand creation was also found to be a weak "service delivery process" in the 2013 WSP evaluation mentioned previously. Additionally, the Planning Commission study findings also exposed concerns about the reliability of the ODF status as an estimated 13.8% households of the GPs awarded with the NGP or Clean Village Prize reported that some of their family members continued to practice open defecation. Further, not all GPs that had received the award had 100% latrine coverage: 0.65%

reported non-availability of latrines in schools and 17% reported non-availability of latrines in *anganwadis* (government sponsored mother and child care centres). This finding regarding ODF villages that have received the NGP is similar to that in the TARU/ UNICEF study mentioned previously. Lastly, the evaluation also reported on (non) use of latrines in households that have latrines. It was found that 20% of households with latrines reported that at least one family member practices open defecation. Table 3-1 provides a further breakdown of latrine (non) use results among sampled households that have individual household latrines (Planning Commission, 2013).

Table 3-1: Results from the Planning Commission (GoI) evaluation study on non-use of toilets among households that have toilets (sample: 11,519 beneficiary households in 122 districts from 27 Indian states) (Planning Commission, 2013)[2]

HHs with IHHLs available (N)	HHs that expressed unwillingness to use latrine (%)	HHs where latrine is not used daily (%)	HHs where men are not using latrine (%)	HHs where women are not using latrine (%)	HHs where children are not using latrine (%)	HHs with additional latrine requirements (%)
10002	13.5	19.8	18.4	11.6	14.5	11.4
Coefficient of variation across States	95.49	85.22	91.25	91.24	82.83	110.84
Source: Household level data. Coefficient of variation based on % values. HHs with incomplete/ inconsistent information ignored.						

Finally, a recent study, referred to as the SQUAT (Sanitation, Quality, Use, Access and Trends) survey, was conducted among 3235 rural households in 13 districts in five Indian states: Bihar, Haryana, Madhya Pradesh, Uttar Pradesh and Rajasthan, with a

[2] The study assessed relative variability across states by calculating coefficients of variation on the percentage values of the parameters considered and reviewing the percentile distribution of the same. Lower values of the coefficient of variation imply lower variations across states (PLANNING COMMISSION, G. O. I. 2013. Evaluation Study on Total Sanitation Campaign Planning Commission, Government of India.)

view to understanding sanitation behaviours and to probe why open defecation in rural India remains high despite decades of government efforts to stem the problem (Coffey et al., 2014). The study has important implications on latrine use. Firstly, many householders with access to latrines still defecate in the open. It was found that in 56% households everyone defecated in the open; 18% households had some members that defecated in the open while others did not; and in 26% households there was no open defecation at all. Further, person-level statistics estimated that across the states, 21.1% individuals (greater than two years) in latrine owning households open defecate. Secondly, members of households with latrines built with government support were twice as likely to defecate in the open compared to members of households with privately constructed latrines. Thirdly, more than half the survey population reported that they would continue practicing open defecation in the four study states (excluding Haryana), even if the government constructed a latrine in every household. Fourthly, the study population believed that open defecation is "pleasant, healthy and wholesome". Lastly, among non-latrine owners, more than 78% respondents cited cost as a reason for continuing with open defecation. The findings of this study are not dissimilar to the results regarding sanitation practices among latrine owning households in the study by the Planning Commission (Planning Commission, 2013) mentioned previously. They both highlight the centrality of latrine use, rather than an exclusive focus on access and latrine construction, to ensuring sanitary gains and addressing the challenge of open defecation in India.

These findings reflect a consistent gap in understanding of what happens beyond the construction of latrines, including a limited perspective on the use of facilities; by whom, if at all, they are used; and the factors that drive use (refer to Section 3.5). It is only three recent India-based studies conducted by the WSP (WSP, 2013), the GoI (Planning Commission, 2013) and Coffey (Coffey et al., 2014) that have weighed in on this aspect, in acknowledgement of the fact that progress monitoring in sanitation may not be effective without including latrine use as an outcome indicator. Also, given that the GoI has already allocated upward of USD 3,888 million to the TSC (WSP, 2011a), it is important to gauge whether these investments are yielding anticipated sanitary outcomes from a policy perspective. This research seeks to generate evidence on certain aspects mentioned above, including monitoring and measurement of latrine use.

3.2.2 Examples from other countries

This section provides examples from other countries to illustrate the similarity of programmatic and latrine coverage versus use issues to those in India (described in Section 3.2.1).

According to the WHO/UNICEF JMP, approximately half of the population in developing countries do not have access to improved sanitation facilities, namely in South Asia, East Asia and Sub-Saharan Africa (WHO-UNICEF, 2015). However, in an effort to meet their MDG targets and improve nation-wide sanitation status, several countries, similar to India, have undertaken programmes toward this end. As evident from examples of other countries mentioned below, certain programmatic concerns and the emphasis on latrine access versus use emerge as cross-cutting issues.

For example, according to a report by IRC International Water and Sanitation Centre in 2009, Uganda's Poverty Eradication Action Plan prioritises the provision of improved water supply and sanitation services. The report suggested that while the national sanitation coverage figure was 62%, the figure did not reveal important weaknesses or gaps in the programme. The identified issues included the fact that 79% of the latrines lacked hand-washing facilities; there were significant variations in sanitation coverage between Uganda's 80 districts; and that the condition and use of latrines was not accounted for in the reported figures (IRC, 2009). Furthermore, Uganda has also experienced the problem of inconsistencies in data sets related to the measurement of "improved sanitation" coverage when varying national level estimates, between 55% and 85% for 2003, were given by four different agencies (Outlaw et al., 2007, Cotton and

Bartram, 2008). This discrepancy was attributed to the incorporation, or lack thereof, of the latrine use indicator. It was suggested that most of the national household surveys did not consider the use of latrines or respondents did not like to admit to not using them. However, the Health Inspectors' Annual Sanitation Survey did account for households with latrines that were in dis-use, thereby arriving at lower national sanitation coverage figures when compared with the other three agencies (Cotton and Bartram, 2008).

Further evidence of the importance of latrine use and functionality as an indicator to evaluate the functional sustainability of sanitation programmes, as opposed to an (almost) exclusive focus on expansion of new services, emerges from a study done in two districts in rural Ghana (Rodgers et al., 2007). The study included 120 randomly sampled latrine owners and 120 non-owners. All the latrines of the latrine owners were built through the assistance of a sanitation programme. The findings showed that as many as 40% of the latrines were incomplete or not in use. Yet, reported levels of latrine access or ownership included all of these latrines in the overall estimate, thereby presenting an exaggerated and misleading picture of ground realities. This illustrates how excessive reliance on latrine access in programme monitoring, in the absence of a latrine use and functionality indicator, may actually undermine medium/ long-term sanitation efforts and achievement of goals.

In another example, a report by Papua New Guinea’s Rural Water Supply and Sanitation Programme suggests that a majority of its rural population, which is 85% of the total population, lacks access to improved sanitation facilities and defecates in the open (RWSSP, October 2011). The country did not meet its MDG target. In order to meet the Government’s target of access to sanitation facilities by 70% of the population by 2030, an estimated 60,000 rural households will need to be targeted each year after accounting for population growth rate. This is also compounded by various technical, social and economic challenges to ensuring access to sanitation, such as geographical and cultural diversity, low-income levels, etc. Community-led Total Sanitation (CLTS) has been proposed as a solution and was introduced to Papua New Guinea in 2008 and later in 2010. The approach emphasises not only provision of toilets, but also their sustained use and seeks a shift from targeting latrine coverage rates to achieving open defecation free villages. In Papua New Guinea, this approach has not yet received complete support from the government (RWSSP, October 2011).

3.3 Challenges in measuring latrine use

This section will review various approaches that are commonly used to measure water, sanitation and hygiene behaviour at the household level and will highlight the specific challenges in the context of measuring latrine use. Table 3-2, at the end of this section, may be referred to for an overview of measures to assess WASH behaviour.

Structured observation is a commonly used tool to measure WASH behaviour (Curtis et al., 1993). For example, in a study on the effect of soap promotion and a hygiene education campaign on hand washing behaviour in rural India, direct observation was used to collect data on key occasions that were accompanied by hand washing with soap from all study households (Biran et al., 2009). The observations of hand washing after key occasions, as defined in the study, were carried out for 3 hours beginning between 05:00 and 05:30 hours in each study household by trained local female fieldworkers. It was observed that the local female workers were more acceptable to the study householders. In addition, local recruitment also eased logistical challenges of observing behavioural events or practices that are likely to occur early in the morning or evening. The study participants were only told that “routine domestic practices and child care” were being observed, rather than the exact nature of data being sought, thereby increasing the validity of the data (Biran et al., 2009).

In a research on the sustainability of hygiene promotion activities undertaken several years prior in countries in Africa and Asia, the tools were selected in order to minimise alteration in behaviour among respondents (Awunyo-Akaba et al., 2004, Cairncross and Shordt, 2004). The researchers used direct observation. They ensured that their observations were "focused" and "structured", wherein the observations were directed at what needed to be known and they followed a fixed plan with observation check-lists to ensure that "things were observed in a thorough, efficient and un-biased way" (Awunyo-Akaba et al., 2004). Another study that explored the relationship between hygiene behaviour and diarrhoeal diseases in Botswana used semi-structured observation, among other methods, which included as many as three visits to each family lasting up to three hours each and provided very rich information on hygiene behaviour (Kaltenthaler and Drašar, 1996).

A study in Burkina Faso comparing data on hygiene practices obtained from questionnaires and structured observations found that questionnaire data is less valid than observation data (Curtis et al., 1993). However, it also highlighted the variability of behaviours and the need for repeated observations in such contexts (Curtis et al., 1993, Cousens et al., 1996). In a study in Bangladesh that compared questionnaire data with those obtained by direct observation of practices related to water storage, hand-washing and defecation showed significant dis-agreements between the results of questionnaires and observations (Stanton et al., 1987). Based on a single observation per household, the researchers concluded that questionnaires tend to result in over-reporting of desirable practices among respondents and should therefore not be used as proxies for direct observation.

However, observations may not be suited to large scale studies and are impractical to monitor a private behaviour like latrine use. Some research suggests that it results in reactivity in behaviour (Pedersen et al., 1986, Munger and Harris, 1989, Edwards et al., 2002, Larson et al., 2004). This has also been found, with specific reference to latrine use, in a pilot study that compared a smart device to assess latrine use with structured observations. The study findings revealed that latrine use by householders was more frequent during periods of observation (Clasen et al., 2012b). In order to overcome this bias, repeated observations have been proposed as an approach as they allow a subject to get sufficiently accustomed to the presence of the observer and revert to usual practices (Cousens et al., 1996). Nevertheless, structured observation is expensive, resource intensive and time-consuming, particularly over the long-term (Curtis et al., 1993, Larson et al., 2004).

Self-report measures, such as a diary or questionnaire, have also been used to measure health practices at the household level. Some studies have used this method as a complementary approach in conjunction with other approaches. For example, in the hand washing study mentioned above, self-reported soap use was assessed at baseline and after the campaign in a sub-sample of 10 households per village, along with other methods used in the overall study, such as structured observations and electronic soap loggers (Biran et al., 2009). The approach was also used, following a questionnaire format, in a knowledge, attitudes and practices (KAP) study to assess water usage, sanitation and defecation practices in a southern Indian rural community (Banda et al., 2007). More recently, self-report, along with sanitary surveys, was used in the context of a cluster randomized trial to assess the effect of India's TSC on defecation behavior and child health in rural Madhya Pradesh (Patil et al., 2014). The researchers asked about open defecation by demographic categories, comprising men, women and children under five. Households were queried for each group separately about whether they open defecate "daily/ always, occasionally/ seasonally, never" (Coffey and Spears, 2014). A recently concluded "SQUAT survey" was used to collect data in five States in rural north India (also referred to in Section 3.2.1.2) to assess the persisting sanitation challenge of open defecation in the country (Coffey et al., 2014).

Other researchers have developed a self-report survey-based instrument, referred to as the "Safe San Index", to measure and quantify the degree of safety of excreta disposal behavior of households in the Indian context (Jenkins et al., 2014). A recent review of the implications of survey questions, design and methodology for developing a quality survey of open defecation in India, emphasised the importance of “disaggregation of the survey question” (Coffey and Spears, 2014). This analysis revealed that asking “balanced” individual level questions about each household member offers more useful data than either grouping people together into demographic categories or asking broad-based household level questions. Thus, the potential richness and depth of reported use data makes it an invaluable and popular measure.

However, self-reported measures too have limitations. Some studies indicate that they are variable, biased measures with a tendency to over-report desirable behaviour (Curtis et al., 1993, Manun'Ebo et al., 1997, Scott et al., 2008, Schmidt and Cairncross, 2009, Patil et al., 2014, Bartram et al., 2014) and influence the behaviour being monitored (Dombrowski et al., 2012, Zwane et al., 2011, Michie et al., 2009).Repeated interviews or completing a diary and ensuring that recordings are not missed may be burdensome to investigators and subjects, leading to fatigue and thereby reducing reliability (Zwane et al., 2011). Further, household-based surveys that are often used to elicit such information tend to be time-consuming and expensive (Bartram et al., 2014).

Trachoma-related research that has assessed latrine use has typically relied on sanitary surveys and latrine inspections, which include observable indicators such as the presence of faeces, flies, well-worn path to the latrine (O'Loughlin et al., 2006), cleanliness of the latrine floor, hand-washing facilities (Montgomery et al., 2010), odour, anal cleansing agents, water to flush (USAID, 2010, Patil et al., 2014), absence of storage materials, door in good repair or closable and absence of spider webs (Billig et al., 1999), among others. Evidence of fresh faeces in the pit (Montgomery et al., 2010) or measuring the quantity of faeces and pit fill rate (Todman et al., 2014) is not always feasible given that pits are sometimes inaccessible. In addition to latrine inspections, some survey protocols also include observing the presence of human and/or animal faeces in the household living area or compound (Patil et al., 2014).

Another recent study that used latrine inspections to assess household level use relied on similar indicators comprising “smell of faeces, wet pan except when rainy, stain from faeces or urine, presence of soap, presence of water bucket or can, presence of a broom or brush for cleaning, or presence of slippers" (Clasen et al., 2014). In the studies reported by both Patil (Patil et al., 2014) and Clasen (Clasen et al., 2014), the IHHLs were directly inspected by the surveyors, thereby increasing the quality of the data obtained if the surveyors are trained. However, others have argued that given the social taboo associated with latrines in some cultures, where they are considered to be “dirty and polluting places”, mandatorily requiring direct inspections may compromise the commitment and output quality of the surveyors (Coffey and Spears, 2014). A recent study has also reported that repeated spot-checks have the potential to cause reactivity in longitudinal studies (Arnold et al., 2015). Finally, although latrine inspections serve as an efficient measure of household use, they do not enable individual level understanding of sanitation behavior that is also important (Clasen et al., 2014) .

Although not a conventional approach, interviews with key informants can help understand and describe behavioural occurrences within a community and the reasons behind the practices (Cairncross and Shordt, 2004). It may be particularly valid for socially sensitive behaviours (Curtis et al., 1993). Thus, village informants of both genders may offer insight into the defecation behaviours being practiced by the community, including the extent of latrine use and open defecation. However, the limitations of these methods are that they are often subjective, lack required sensitivity and specificity and do not help in determining patterns of use over extended periods (Clasen et al., 2012b).

Another method that is also not commonly used in the WASH sector is “pocket voting” (Awunyo-Akaba et al., 2004). It was used as a research tool to assess the sustainability of hygiene behaviour several years after the intervention was implemented. It consists of a cloth chart with a row of pockets beneath pictures showing, for example, possible sites of defecation: forest, stream, open field, latrine etc. When used in India, this chart was left in the household to enable family members to vote confidentially while the field team continued with other activities. Men, women and children used three different colours of paper to enable group level analysis. The chart was carried from house to house to enable similar "confidential" voting by men, women and children in all households in the study population. The researchers found that this method reduces the likelihood of bias since voting is done anonymously. For example, it was found that by using this method in India, fewer people claimed to wash their hands with soap than when directly questioned. It is not likely to alter behaviour if the outcome is not discussed with the respondents. It also allows a semi-dis-aggregated level of analysis at the household level offering useful insights into hygiene behaviour and practices (Awunyo-Akaba et al., 2004). However, the feasibility of using this method on a large scale may be limited. Further, to my knowledge there appears to be no evidence to suggest that this method has been validated.

Recent technological developments, such as the use of unobtrusive sensory devices to monitor behaviour, have the potential for overcoming some of the shortcomings of other methods of assessing WASH behaviours (Judah et al., 2009). For example, electronic soap loggers, which were embedded in the soap of participants in a study on hand washing behaviour in rural India, were used to monitor hand washing after faecal contact, eating or giving food to a child (Biran et al., 2009). The study households were informed that the soaps contained electronic devices that recorded soap movements. The loggers were also attached to water cans used for anal cleansing. If soap movement occurred within 5 minutes of the use of the water can, it was assumed to represent soap use after defecation. This study, which was a pilot test of the device, did not report on potential limitations of using the soap logger, such as acceptability among study participants that may be indicated by refusal to participate, device failure rate or the potential influence on the target behavior being measured. Another example, the

University of California, Berkeley "Time-Activity Monitoring System" (UCB-TAMS) has been used in studies to assess indoor air pollution, which monitors time that householders spend in close proximity to cooking stoves. These devices are useful as they can provide data not only on the entire household but also at an individual level, thereby helping identify refractory members (Allen-Piccolo et al., 2009). Further use of technology, in the form of remotely reporting electronic sensors, was made in a study in Rwanda that assessed use of water filters and cookstoves in households (Thomas et al., 2013b). It was found that the sensor-collected data estimated a lower level of use than that obtained from surveys and direct observation, suggesting that these two methods may exaggerate household compliance with the products being studied. Studies involving Stove Use Monitors (SUMs), such as temperature data-loggers, to quantify adoption and use of biomass cookstoves have also been conducted (Ruiz-Mercado et al., 2013, Ruiz-Mercado et al., 2012). The evidence suggested that qualitative indicators of use from recall questionnaires were consistent with SUMs measurements, indicating questionnaire accuracy. Another study in India that used SUMs in the form of small, unobtrusive data-logging iButton thermometers to monitor use patterns of the advanced and traditional cookstove found it to be an effective measure of consistent long-term use (Pillarisetti et al., 2014). An earlier study used a ceiling-mounted video camera surveillance system to assess whether entrants to an intensive care unit followed the rule of washing their hands prior to entry over a 7 day period (Nishimura et al., 1999). Thus, there was no selection bias and large spaces could be viewed at once. However, there may be concerns about privacy for patients and staff and it may present technical problems in clinical settings. Generally, despite the potential advantages of such technology-based monitoring systems, often their cost, limited battery life, fragility, and acceptability of these devices make them challenging to use in low-income settings.

The Passive Latrine Use Monitor (PLUM), described in detail in Chapter 5, was developed and tested by Clasen and colleagues to measure latrine use in a field trial in

Odisha, India (Clasen et al., 2012b). This device was compared with direct observation. The findings indicated that unlike direct observations, which generated 5 hours of data per household observed, the PLUM provided continuous data for the entire 7 days of monitoring of each household. In addition, the frequency of latrine events by household members increased significantly in the presence of an observer. The researchers therefore inferred that structured observations resulted in reactivity among study participants. However, the increasing use of electronic sensors to monitor environmental health interventions has also raised questions regarding the effect of the sensors on research participants' behaviour. Evidence from a recent cluster randomised trial suggests the presence of behavioural reactivity associated with electronic monitoring (Thomas et al., 2016).

Another recent study used a combined methodological approach, including ethnographic interviews and PLUMs, to estimate latrine usage in rural India (O'Reilly et al., 2015). This study was conducted in West Bengal and Himachal Pradesh, India, and included 258 households where the sensors were installed for a minimum of 6 days. Ethnographic and observational methods to capture defecation practices and meaning in the study population were used to frame the analysis of the PLUM data. The researchers concluded that the PLUM data provided reliable quantitative verification while the interviews offered unique information and understanding of latrine use in the study population. It may be mentioned here that the version of the PLUM used in this study was the same as that used in our research. I was involved in the PLUM-related aspects of the above mentioned study, specifically validation of the algorithm to estimate likely defecation events, developing a definition of a "functional latrine", finalising PLUM installation and removal protocols, the PLUM training modules for the field teams, offering on-going field-based technical support regarding collection of the raw PLUM data. A copy of the paper has been included in Appendix 2.

There is very limited research to date that comprehensively validates the various methods for assessing latrine use, reports on its diagnostic capacity (e.g., sensitivity and specificity) and compares one method against another method. As described more fully in Chapters 5 and 6, I will use a combination of methods for assessing latrine use. I will also compare these methods to assess latrine use with a view toward providing guidance to researchers, implementers, funders and policy makers on which method(s) may be most suitable for assessing latrine use.

Table 3.2: An overview of measures to assess WASH behaviour

Method	Description	Examples	Country	Advantages	Dis-advantages
Structured observation	Observations are "focused" (directed at what needs to be known) and "structured" (follow a fixed plan with observation check-list).	Stanton et al. (1987)	Bangladesh	Most direct measure of behaviour, thereby reducing bias. Repeated observations can reduce mis-classification of exposure status.	Results in behaviour change or reactivity in participants unless observation is clandestine. Expensive. Time-consuming. Resource intensive. Single observation does not account for within individual variability in behaviour.
		Curtis et al. (1993)	Burkina Faso		
		Cousens et al. (1996)	Burkina Faso		
		Kaltenthaler and Drašar (1996)	Botswana		
		Awunyo-Akaba et al. (2004) Cairncross and Shordt (2004)	Multi-country (Africa and Asia)		
		Larson et al. (2004)	USA		
		Biran et al. (2009)	India		
Self-report	Relying on respondent recall, this may be in the form of an interview, questionnaire or survey, diary entries.	Banda et al. (2007)	India	Inexpensive. Efficient. Potential to obtain a large sample size. Recall bias reduced with diary format/ question	Poor reliability and validity: prone to bias (surveyor bias, courtesy bias, social desirability bias, recall bias, Hawthorne effect and "survey effect"). Repeated interviews or
		Biran et al. (2009)	India		
		Planning Commission (2013)	India		
		Patil et al. (2014)	India		
		Coffey et al. (2014)	India		

		Jenkins et al. (2014)	India	about "last time". Potential to offer varying levels of data based on the research objective and type of questions asked: comprehensive household level data without dis-aggregation; semi-dis-aggregated data, fully dis-aggregated data at the individual level.	surveys may result in investigator and respondent fatigue.
Latrine inspections or spot-checks	Assessment at a given time point based on observable indicators of use: Well-worn path between the house and the sanitation facility. Signs of wear on the seat. Absence of storage materials. Door in good repair.	Billig et al. (1999) (Water and Sanitation Indicators measurement Guide)	NA	Efficient measure of household use. Direct inspections by trained surveyors can increase the data quality.	Does not permit individual level understanding of use behaviour. Cultural reservations about inspecting "dirty, polluted" latrines may compromise output quality of surveyors. Latrine pits may be inaccessible and not directly visible, preventing direct

	Absence of spider webs, among others.				inspection. Does not offer an extended perspective of use.
	Inspection of structure and usability. Presence of faeces and/or flies. Well-worn path to the latrine.	O'Loughlin et al. (2006)	Ethiopia		
	Trail (well-worn path between household and latrine). Presence of fresh faeces in the latrine pit. Complete super-structure and privacy. Clean floor. Roof (with no holes larger than the size of an adult's fist). Drop-hole cover. Hand-washing facility within 1m of latrine.	Montgomery et al. (2010)	Tanzania		

	Worn path. Closable door. Odour. Anal cleaning material. Water to flush. Human/ animal faeces in the household living area.	Patil et al. (2014)	India		
	Smell of faeces. Wet pan except when rainy. Stain from faeces or urine. Presence of soap. Presence of water buckets or can. Presence of a broom or brush for cleaning. Presence of slippers.	Clasen et al. (2014)	India		

	Quantity of faeces and pit fill rate.	Todman et al. (2014)	Tanzania		
Informant interviews	Elicits information about behavioural occurrences in a community, the reasons behind them, the links between behaviours and health and change in behaviour over time.	Cairncross and Shordt (2004)	Multi-country (Africa and Asia)	Valid for socially sensitive behaviours.	Often subjective. Lack required sensitivity and specificity. Do not help in determining patterns of use over extended periods.
Pocket voting	Consists of a cloth chart with a row of pockets beneath pictures showing, for example, possible sites of defecation: forest, stream, open field, latrine etc. Enables confidential voting where men, women, children may use different coloured votes.	Awunyo-Akaba et al. (2004) Cairncross and Shordt (2004)	Multi-country (Africa and Asia)	Reduces bias since voting is done anonymously. Enables semi-disaggregated analysis at the household level, for example, by demographics.	Feasibility of using this method on a large scale may be limited. Evidence regarding validation of method appears to be lacking.
Technology-based measures*	Video camera surveillance system (to monitor hand-washing).	Nishimura et al. (1999)	Japan	Offers an extended perspective of use. Reliable and valid	Early stage products/ prototypes may be costly.

	Electronic soap loggers(embedded into soap to monitor hand-washing).	Biran et al. (2009)	India	measure, especially if pilot tested against structured observations. Potential to monitor in real time. May be unobtrusive (except for video surveillance). May be used in combination with qualitative measures to deepen understanding of behavioural practices and social norms.	Limited battery life. Not robust to withstand harsh weather conditions. Low acceptability in households. Not always possible to track specific individuals. Potential behavioural reactivity of participants to sensor monitoring.
	Time-Activity Monitoring System (to assess indoor air pollution: monitors time householders spend in close proximity to cooking stoves).	Allen-Piccolo et al. (2009)	Gautemala		
	Passive Latrine Use Monitor (PLUM) (to monitor latrine use).	Clasen et al. (2012)	India		
	PLUM and ethnography (combined methodological approach to estimate household latrine usage)	O'Reilly et al., 2015	India		
	Remotely reporting electronic sensors (to assess use of water filters and cook-stoves in households).	Thomas et al. (2013)	Rwanda		

	Temperature dataloggers - Stove Use Monitors(SUMs)(to quantify usage of biomass cookstoves)	Ruiz-Mercado et al. (2012, 2013)	Guatemala		
	iButton thermometres – SUMs(to assess patterns of advanced and traditional stove usage)	Pillarisetti et al. (2014)	India		

***Examples of the use of sensors to monitor cookstove use have been included as the technology is also relevant to WASH monitoring**

3.4 Household latrine use and health outcomes

The body of evidence relating latrine use specifically to infection or disease is relatively limited. Until recently, only a few studies in the field of trachoma, a leading cause of preventable blindness, had explored this association. *Musca sorbens*, the eye seeking fly and the carrier of the trachoma bacteria, mainly breeds in human faeces.

In general, studies that assessed latrine *use* reported it to be associated with reduced transmission of trachoma. A cluster randomised trial conducted in a trachoma endemic rural region of The Gambia assessed the role of eye-seeking flies as vectors of trachoma and tested if the provision of simple pit latrines, in the absence of additional health education, may be a sustainable method of fly control (Emerson et al., 2004). Latrine uptake was monitored by weekly visual inspections for the first month, followed by monthly inspections subsequently. The latrine use indicators considered in this study were the presence of adequate screening, faeces in the pit, flies around the slab and a well-worn path to the latrine. The findings of the study indicated that the number of *Musca sorbens* flies caught from children's eyes was reduced by 30% (95% CI = 7, 52, p = 0.04) by provision of latrines when compared with controls. Additionally, cluster level age-standardised trachoma prevalence rates showed that latrines were associated with a 30% (-81 to 22, p = 0.210) mean reduction in trachoma prevalence in comparison to the mean rate change in controls. These results suggested that provision of latrines is associated with a significant reduction in fly-eye contact by *M. sorbens* (Emerson et al., 2004).

A case-control study in rural Tanzania reported latrine use to be significantly associated with decreased risk of trachoma (Montgomery et al., 2010). Latrine use was found to be greater in control than in case households (90.4 vs. 76.8%, p=0.03). The protective effect of latrine use persisted even after controlling for potential confounders, including number of children aged less than 10 years, head of household's education level, cumulative wealth score, distance to primary water source, presence of garbage pit and cattle-keeping near house (adjusted OR=0.56,95% CI 0.32, 0.98, $p < 0.20$). The potential impact of latrine quality on transmission of trachoma was also assessed. Seven latrine elements, including a trail to the latrine, fresh faeces, complete superstructure, clean floor, roof, drop-hole cover and hand-washing facility were assessed. Latrine quality was not associated with decreasing odds of disease. Rather, overall latrine use, irrespective of the hygienic quality of the latrine, was associated with decreased risk (Montgomery et al., 2010).

Another study conducted in South Sudan found that after adjusting for age, sex, and district baseline prevalence of active trachoma, the presence and use of pit latrines in households was independently associated with 60% reduction in relative odds of active trachoma (OR=0.4, 95% CI 0.2, 0.9, p=0.031) (Ngondi et al., 2008b). In this study too, the presence and use of pit latrines at the household level was ascertained by observation.

Thus, while all the studies provided some evidence of the protective effect of latrine use on the risk of trachoma, the primary methods employed to determine use were sanitary surveys and latrine inspections, which lack sensitivity and specificity and offer a relatively subjective and limited perspective of use.

On the other hand, studies conducted in Mali (Schemann et al., 2002), Ethiopia (Ngondi et al., 2008a), Burkina Faso (Schémann et al., 2003), Niger (Abdou et al., 2007), Senegal (Faye et al., 2006) and the Gambia (Harding-Esch et al., 2008) that all assessed household *ownership* of latrines did not find a significant association between latrine ownership and active trachoma. For example, the study conducted in Mali (Schemann et al., 2002) found that in an initial univariate analysis, latrines had a protective effect. Trachoma was less frequent and less intense in households with latrines (active trachoma: OR = 0.78, 95% CI = 0.72, 0.84; intense trachoma: OR = 0.72, 95% CI = 0.61, 0.85). However, the final multivariate analysis of risk factors for active trachoma revealed that the absence of latrines did not show a harmful effect.

Three important studies conducted in the past 4 years in India have also found no evidence on the association between household level latrine coverage/ availability and health outcomes.

A matched cohort design study of 25 villages that estimated the impact of a non-randomised, pre-existing village-level WASH promotion programme in rural Tamil Nadu, India, found that although there was 33% difference in new latrine construction between the intervention and control arms during the period 2003-2008, the intervention did not have an impact on the height-for-age and weight-for-height Z score or diarrhoea prevalence in children <5 years (Arnold et al., 2010). The study findings also showed that in intervention villages, which had all been declared "open defecation free," adult open defecation ranged between 35% and 83%, thereby implying inadequate use of latrines.

A cluster randomised trial that was conducted in Odisha to assess the effectiveness of a rural sanitation intervention to prevent diarrhoea, soil-transmitted helminth infection and child malnutrition, found no evidence of the effect of the intervention, neither from village-level coverage nor from presence of IHHL, on the health outcomes of interest (Clasen et al., 2014). A plausible explanation for the absence of effect cited by the researchers was the "insufficient coverage and use of latrines". It was found that in the intervention villages, the mean proportion of households with a latrine increased from 9% (baseline) to 63% (follow-up). However, at follow-up only 11 of a total of 50 intervention villages had functional latrine coverage of 50% or greater. Since latrine functionality may be considered as an objective measure of use at a household level, the findings implied that use was likely to have been sub-optimal, thereby resulting in continued exposure to faecal pathogens (Clasen et al., 2014).

Another cluster randomised trial that was also conducted in the context of the Indian Government's TSC in Madhya Pradesh had similar findings (Patil et al., 2014). This study aimed to measure the effect of the TSC on the availability of IHHLs, defecation behaviours and child health measured in terms of multiple health outcomes. The results suggested that there was an average 19% increase in households with improved latrines in the intervention arm (95% CI for difference: 12%-26%, $p < 0.001$; group means: 22% control versus 41% intervention). There was also an average 10% decrease in open defecation among adults in the intervention arm (95% CI for difference: 4%-15%; group means: 84% control versus 73% intervention). However, there was no evidence of impact on child health as measured by the health outcomes. Defecation behaviours were assessed by self-report measures and included queries on child faeces disposal. Latrine use was assessed based on latrine inspections by the surveyors. Overall, the researchers found that reductions in reported open defecation were smaller than the increases in IHHL availability, which they attributed to likely cultural-habitual preference for open defecation and inadequate water availability (Patil et al., 2014).

Table 3.3 provides a summary of the studies related to latrine use and health outcomes that have been reviewed in this section.

Table 3.3: Summary of studies on household latrine use and health outcomes

Study*	Setting	Design	Primary outcome measured	Latrine coverage	Latrine use	Health impact
Emerson et al., 2004	The Gambia	Community-based cluster randomised controlled trial	Fly-eye contact, prevalence of active trachoma	All households in latrine arm received latrines	98% latrines in latrine arm showed signs of use over 6 months	Flies caught from children's eyes: 30% reduction (95% CI = 7, 52, p = 0.04) by provision of latrines vs. controls. Age standardized trachoma prevalence rates: 30% mean reduction (-81 to 22, p = 0.210) vs. controls
Montgomery et al., 2010	Tanzania	Case-control	Active trachoma	-	Latrine use greater in control than in case households (90.4 vs. 76.8%, p = 0.03)	Protective effect (adjusting for confounders): adjusted OR = 0.56 (95% CI = 0.32, 0.98, p < 0.20)
Ngondi et al., 2008	Southern Sudan	Cross-sectional	Severity of active trachoma signs	6.3% households had pit latrines	-	Households using pit latrines: 60% reduction in relative odds of active trachoma (OR=0.4, 95% CI = 0.2, 0.9, p = 0.031)
Arnold et al., 2010	India	Matched cohort design	Height-for-age and weight-for-height Z score, diarrhoea prevalence in children <5 years	33% increase in new toilet construction in intervention households vs. controls	Intervention ODF villages: adult open defecation ranged between 35% and 83% implying low levels of latrine use	No difference between intervention and control groups: Adjusted difference in height = 0.01, 95% CI = -0.15, 0.19; in weight – 0.03, 95% CI = -0.11, 0.17 Adjusted estimates, LPD =

						0.003, 95% CI = -0.001, 0.008 Mean prevalence = 1.8%
Clasen et al., 2014	India	Cluster randomised trial	7 day prevalence of reported diarrhea in children < 5	Mean village-level latrine coverage: Intervention villages - increase from 9% households to 63% Control villages – 8% to 12 %	63% households with latrines in the intervention group reported using it	No difference between intervention and control groups. 7 day period prevalence of diarrhoea in < 5s: 8.8% - intervention group, 9.1% - control group (period prevalence ratio = 0.97, 95% CI = 0.83, 1.12)
Patil et al., 2014	India	Cluster randomised trial	Diarrhoea, HCGI in < 5s	19% increase in households with improved latrines in the intervention arm (95% CI for difference: 12%-26%, p < 0.001)	Approximately average 10% greater (interviewer assessed) use of latrine in intervention arm (95% CI for difference: 5-16), average 10% decrease in open defecation among adults in the intervention arm (95% CI for difference: 4-15)	No difference between intervention and control groups: diarrhoea prevalence was 7.4% intervention vs. 7.7% control, p = 0.687 HCGI prevalence was 11.5% intervention vs. 12.0% control, p = 0.692

LPD = Longitudinal prevalence difference, HCGI = Highly credible gastrointestinal illness (including vomiting, watery diarrhoea, soft diarrhoea and abdominal cramps, or nausea and abdominal cramps)

*Six studies (not included in the table) that assessed household ownership of latrines did not find a significant association between latrine ownership and active trachoma.

Some findings suggest that contamination by even a relatively small percentage of the community who continue to practice open defecation can compromise health gains. Evidence for this may be found in studies that have found high prevalence of stunting (when compared with healthy norms) among privileged children (the richest 2.5%) in urban Indian households that use toilets (Spears, 2012, Spears et al., 2013). Another formative research study undertaken by WSP-Knowledge Links in Himachal Pradesh, India, in 2005, found that rural households in the state with limited or even 100% latrine coverage reported a high recall of diarrhoea incidence (Sanan and Moulik, 2007). Only ODF villages that also reported 100% latrine use reported a significant drop in diarrhoea recall (Table 3-4).

Table 3-4: Individual sanitation practices affect the entire community
(Source: Formative research by WSP-Knowledge Links for IEC Manual in Himachal Pradesh, 2005)

Category	**Users of toilets (%)**	**Prevalence of diarrhoea (%)**
Open defecation prevalent villages	29	38
Almost open defecation free villages	95	26
Open defecation free villages	100	7

It has been asserted that for maximum impact, sanitation needs to be practised by at least 75% of households in a given community (Bateman and Smith, 1991), if not by all; it needs to endure with time [similar to water quality interventions (Brown and Clasen, 2012)]; and that the technologies used must prevent environmental pollution (Bartram et al., 2005, Cotton and Bartram, 2008). This is especially problematic in rural India where children, among others, continue to practise open defecation (Clasen et al., 2012b, WSP, March 2015). It has been suggested that reasons for this may be that privacy is viewed as un-important to them and child faeces is often considered benign, making its safe disposal low priority (Alok, 2010). Findings from a UNICEF study conducted in NGP villages in India revealed that only 55% of study population households reported use of latrines by children or disposal of child faeces in the latrine; 41% reported disposal of faeces in the open or along with solid waste; and 3% reported disposal of faeces in the drain (TARU, 2008). A more recent small scale (n=136 households) cross-sectional study in rural Odisha to explore disposal practices of child faeces in villages where the Indian TSC programme had been implemented at least three years prior to the conduct of the study also showed that latrine ownership did not guarantee safe disposal of child faeces. Only 24.5% households with latrines reported safe disposal of faeces of children (Majorin et al., 2014).

These studies suggest that the distinction between latrine ownership (or access) and use is an important consideration in terms of its impact on health. As noted in the literature review, there is extensive evidence of non-use, even among households that have latrines. Reliance on a latrine ownership or access metric may result in over-estimation of use, given that not all members of the household may actually use the facility (Coffey et al., 2014, Jenkins et al., 2014, O'Reilly et al., 2015). Ownership or access also provides no information on the extent to which use is rare, occasional, frequent or exclusive. And even a partial non-use or occasional non-use by some otherwise compliant members of the community could result in sufficient levels of contamination to overcome the benefits of sanitation by others. These issues point to the need to measure latrine use, and not only rely on ownership, to evaluate potential associations with health outcomes.

In conclusion, latrine use, especially if practiced by all at both household and community levels, may potentially result in health gains. However, the paucity of research in this area points to the need for additional studies to address the gap. In addition, the current body of work also indicates the need to measure an extended perspective of latrine use by employing a more objective, sensitive and specific method.

3.5 Determinants of latrine use

This section will examine relevant evidence related to determinants of latrine use, with special focus on the determinants that have been considered in this study. These range from demand and supply-related factors to structural issues. It is noteworthy that contrary to the widely held belief that health is likely to be the main selling point for householders to adopt and use latrines, this is rarely the case (Mara et al., 2010). The literature below will reveal some of the main motivations for sanitation adoption and use.

According to research conducted in Benin, West Africa, the motives or reasons for latrine adoption, conceptualised as 'consumer drives', are a result of physical and social conditions of the village environment, individual life-style goals and past latrine exposure (Jenkins and Curtis, 2005, Jenkins and Cairncross, 2010). The research identified 11 different drives and their underlying beliefs and attitudes, which were categorised into 'prestige, well-being, and situational goals'. The study reported that at least one drive was required to motivate for latrine adoption and that health considerations only played a minor role. The drives were found to vary with gender, age, occupation, life-stage, travel experience, education, wealth and income, and the physical and social geography of the village environment with reference to the availability of good defecation sites around the home and/or villages.

A study conducted in Amhara, Ethiopia, which compared characteristics of early adopters with non-adopters, found that latrine ownership and use was associated with education, relative wealth, urban residence and history of travel (O'Loughlin et al., 2006). More specifically, household heads with any education, including non-formal, were 1.9 times (95% CI = 1.3, 2.8) more likely to own and use a latrine than those who did not have a latrine or did not use it. Larger households, with more than 5 members, were 1.5 times (95% CI = 1.1, 2.0) more likely to use a latrine than families with 5 or fewer members. The study also revealed that the odds of finding a neighbouring household without a latrine was 4.7 times (95% CI = 2.0, 11.1) higher in rural than in urban clusters. In addition, the study findings indicated that households with an iron sheet roof (OR = 2.4, 95% CI = 1.5, 3.7) and households with no cattle (OR =2.1, 95% CI = 1.0, 4.6) were also more likely to own and use a latrine. Lastly, an association between ownership and use was also found if the head of the household had a history of travel (OR = 2.5, 95% CI = 1.1, 5.9). It may be relevant to highlight here that latrine use was verified by observing the presence of faeces and/or flies and a well-worn path to the latrine (O'Loughlin et al., 2006).

In a study conducted in rural Tamil Nadu, India, to estimate the impact of a non-randomised, pre-existing village-level WASH promotion programme, it was found that in private latrine owning households, 39% reported that adults practice daily open defecation and 52% reported that children under five years practice daily open defecation (Arnold et al., 2010). The cited reasons for non-use of latrines included no choice (50%), privacy (26%), convenience (25%), and safety (9%). Moreover, 81% private latrine owners reported that women and girls feel safe while defecating during the day or night compared with 53% households without private latrines. This finding under-scores the importance of gender based determinants of latrine use.

Evidence from a survey in rural north India about Sanitation Quality, Use, Access and Trends pointed to the “revealed preference” for open defecation even among latrine owning households in the five states that were surveyed: Bihar, Haryana, Madhya Pradesh, Rajasthan and Uttar Pradesh (Coffey et al., 2014). Since the findings of this study, albeit also relevant to understanding the determinants of latrine use, have already been referred to earlier in Section 3.2.1.2, they will not be repeated here.

Recently conducted research that examined defecation patterns of a rural population in Odisha, India, to gain insights into potential reasons for latrine non-use in the context of the GoI’s TSC intervention, found that certain habits, socialising, sanitation rituals, varied with caste, gender, marital status, age and lifestyle and constrained latrine adoption (Routray et al., 2015). Latrine construction at the household level was motivated by privacy, convenience and security concerns for female members of the household, especially newlywed daughters-in-law. This study revealed the role of socio-cultural and behavioural factors that may present barriers to latrine adoption in the region.

In a review of the progress of sanitation in India, comparing data from Census 2001 and 2011, the evidence suggests a state-level association between access to sanitation and socio-economic status (SES) of the household (Ghosh and Cairncross, 2014). It was found that the percentage of households with a latrine in each state is strongly correlated with the state's wealth concentration index ($r = -0.924$, $p<0.001$). The reviewers also found an inverse relationship between female literacy rates and the prevalence of open defecation at the district level: districts with higher female literacy rates had lower prevalence of open defecation. This revealed the role of not only SES but also education as a potential determinant of latrine use.

Another recent study conducted in rural West Bengal and Himachal Pradesh, India, used ethnographic and technology-based measures to understand the elements of successful sanitation in India (O'Reilly and Louis, 2014). The analysis is based on the premise that in order to understand toilet adoption and sustained use, individual choices should be viewed as a combined outcome emanating from their social, political and environmental context. Therefore, the confluence of "multi-scalar political will" ranging from international to local or *Panchayat* level will to govern; "proximate social pressure driven by economic change", which includes greater wealth, improved connectivity between rural and urban areas and proximity to neighbours/ relatives; and "political ecology", such as land use changes, greater access to water and individual household's sewage management abilities; influence the successful adoption and sustained use of latrines.

The significance of the determinants of latrine use has also emerged in studies conducted in the context of large-scale, government subsidy-driven campaigns, which observed low levels of use despite increased latrine coverage (Banda et al., 2007, Coffey et al., 2014, Routray et al., 2015). Findings from a TARU/UNICEF study revealed little relationship between financing mechanisms and latrine use and maintenance (TARU, 2008). It has been argued that subsidies, unless combined with other drivers, are found to be less effective in motivating latrine use among people (Mitra, 1998, Pattanayak et al., 2009).

However, these motives or drives will result in demand for (and subsequent use of) latrines only if supply-related and structural issues are also simultaneously addressed. This was echoed in an address made by the Prime Minister of India at a sanitation conference in 2008 where he highlighted that 20% of latrines built under the GoI's sanitation programme were not functional due to a variety of reasons, ranging from poor construction to inadequate maintenance (Prime Minister of India, 2008) and were therefore unlikely to be used. A UNICEF supported study conducted among a tribal population of Odisha highlighted some programme-related systemic and supply-side challenges (ICRA, April 2011), including lack of knowledge about the TSC government scheme and how to avail it; an inadequate number of rural sanitation marts at the village-level resulting in unavailability of construction materials; and a poor understanding of the design and construction process of the recommended latrines. Among latrine-owning households, the reasons for low use were also probed: 62% respondents cited insufficient availability of water for flushing and cleansing purposes; 38% reported issues with the design of the latrine and 30% felt that the location of the toilet was inappropriate. An estimated 95% of households reported practising open defecation. Reported challenges associated with it included a danger of snake or animal bites, inconvenience at night and during the rainy season, and problems for the sick and elderly (ICRA, April 2011). The latter issues resonate with some of the demand-related "drives" that were identified in the study in Benin.

A study conducted in rural Tamil Nadu, India, on the knowledge, attitudes and practices regarding water handling, sanitation and defecation behaviour also revealed certain structural factors such as, poor quality latrine construction where pits were not covered or connected to septic tanks, as well as scarcity of water, as reasons for not using or constructing latrines (Banda et al., 2007). The researchers have argued that in the study population, “the government had attempted to construct toilets for every household…..(but) many toilets hastily constructed by the government were non-functional and hence unusable”. The study findings also showed that only 67.9% households with latrines actually used them, citing additional reasons such as latrine use is not a customary practice, especially among the village elders and concerns about smell and water logging during the rainy season. Additionally, among individuals who reported using latrines, the findings indicated that 68% belonged to the highest socio-economic status while 32% belonged to the middle and lower SES.

A recent national level evaluation of the TSC conducted by the Planning Commission, GoI, revealed the importance of variables such as good design and structural features, such as the presence of a roof, side walls, adequate pit depth and drainage; functional latrine facilities; water availability; and location of the latrine (for example, in the house, located at the back, front etc.), in encouraging use and reducing open defecation (Planning Commission, 2013). Additionally, an interesting, yet counter-intuitive, finding was that the practice of open defecation increased in higher income or APL households. The researchers attributed this to the provision of government incentives/ subsidy to low income or BPL households for latrine construction, resulting in a potential increase in latrine use in that segment (Planning Commission, 2013). However, there is also ample evidence to the contrary.

A study conducted in rural Odisha among 20 villages at least three years after the TSC had been implemented also highlighted the role of structure and functionality as an important determinant of latrine use (Barnard et al., 2013). It was found that “functional latrines”, with walls over 1.5 metres, a closure over the entry, an un-broken and un-blocked pan and a functioning pan-pipe-pit connection were more likely to be used than non-functional latrines (adjusted OR = 25.59, 95% CI = 12.07, 54.26, $p < 0.001$). Among the perceived benefits mentioned both by both latrine owning and non-latrine owning households were health followed by safety and security for women and girls.

Another study conducted in rural Odisha that focused on government subsidised latrines and latrine owners also revealed that “incomplete” latrines with structural deficiencies, such as the lack of a roof, door, adequate walls and provision for water supply in or near the cabin, were considered unacceptable by the owners and were cited as likely reasons for non-use of latrines (Routray et al., 2015).

The findings of a recent systematic review, which included 24 studies that specifically examined the association between latrine use and the structural and design characteristics of sanitation facilities, suggested that better latrine functionality and maintenance, latrine type, newer latrine age and accessibility, cleanliness, privacy and better access to hygiene amenities were associated with higher latrine use relative to poorer sanitation facilities (Garn et al., 2016).

Other investigators undertook a more complete understanding of the determinants of latrine use in the context of the Sanitation Trial (Jenkins et al., 2014). The researchers constructed a Safe San Index that consisted of 15 self-report items and two sub-scales, “Latrine Use Frequency” (LUF) and “Seven-Day Open Defecation Rate”. The scales aimed to generate a quantitative estimate of the proportion of human faecal waste generated in a community that is safely disposed, with 0 signifying no defecation safely captured and 100 signifying all defecation safely captured. The findings suggested that high LUF scores were positively correlated with: a) increasingly positive attitudes towards using latrines as measured by the semantic differential and Likert scale attitude scores (ρ = 0.33 and 0.50, $p = 0.008$ and < 0.00005, respectively); b) increasing satisfaction with the facility and its location (linear $p = 0.013$ and 0.005, respectively); c) greater convenience and access to water (for example, mean LUF was significantly lower when bathing at an off-site water source compared to a facility at home, 52 vs. 73; $p = 0.00005$); d) improved functionality and construction quality of the facility (for example, having an attached bathroom and a fully constructed structure increased LUF by 23% and 40%, respectively, versus no bathroom and an incomplete construction); and e) greater sense of ownership and valuation of the facility (for example, those who gave health and non-health benefits had higher mean LUF scores of 86 and 73, respectively, relative to 55 for those who cited government subsidy as a reason, $p < 0.0001$).

As described more fully below, my work in this area was limited to an investigation of the association between my data on latrine use and select determinants using primary data as well as data from the baseline survey and Sanitation Trial. The specific determinants of latrine use included socio-economic status of the household, education level, scheduled caste/ tribe (dis-advantaged caste-based groups), family size, gender, age, distance of latrine from house, proximity of latrine to water source, functionality and the construction quality of the latrine.

3.6 Summary and way forward

The research and reports summarised in this chapter demonstrate the shortcomings of assessing progress on sanitation simply by counting latrines built. The benefits of sanitation can only be realised if facilities are also used. Moreover, because eliminating exposure to human faeces requires a consistent and community-wide effort, the aim must be use by everyone always. This requires a fundamental shift in strategy, from outputs (coverage) to outcomes and ultimately impact.

The first challenge in making this shift is to test various options for monitoring latrine use with a view toward validating an approach that can be used programmatically. While multiple approaches have been used, there is uncertainty about the reliability of the methods. The second challenge is to describe patterns of latrine use and to explore the possible reasons for such use and non-use. This research aims to address both of these challenges.

4 Research goals and objectives

The overall goal of this research was to advance public health by improving the methods for assessing latrine use in low-income countries and by enhancing our understanding of the patterns and determinants of latrine use in rural India. We also sought to document the level of latrine use among households who received latrines under the GoI's TSC in the context of a cluster randomised controlled field trial (the 'Sanitation Trial') in rural Puri district, Odisha (India).

The research had the following specific objectives:

1. To document how current national and international efforts that monitor progress based on latrine coverage address the importance of capturing and incentivising latrine use.
2. To evaluate the methods of assessing latrine use in low-income settings where uptake has been shown to be problematic.
3. To assess whether and to what extent individuals in households that received latrines constructed under the GoI's TSC in Odisha actually use the same.
4. To describe patterns of latrine use, including gender and age differences, consistency of use and seasonal variation in use.
5. To explore potential determinants of latrine use, in particular, socio-economic status, education, family size, gender, age, distance of latrine from house, proximity of latrine to water source, functionality and the construction quality of the latrine.

This research was conducted in the context of the Sanitation Trial and contributed critical information for the assessment of the TSC as implemented in Odisha. The theory of change that underlies sanitation efforts in such settings is that in order to impact health, facilities that are effective in separating human faeces from the environment must be accessible to and actually used by the entire community at all times (Bateman and Smith, 1991, Sanan and Moulik, 2007, Cotton and Bartram, 2008, Spears et al., 2013). Our assessment of latrine use in the context of the Sanitation Trial will help explain the possible reasons for the lack of a protective effect that we reported (Clasen et al., 2014). It also provides data that can be used in a secondary analysis to explore associations between latrine use and health.

Beyond the Sanitation Trial, however, this research aims to improve the effectiveness of sanitation efforts in low-income countries generally. First, it summarises previous research to demonstrate how existing methods for assessing sanitation progress that focus solely on latrine coverage fall short in assessing the actual potential of sanitation interventions. It also documents that international monitoring of sanitation campaigns rely solely on latrine coverage, thus providing little incentive for ensuring actual uptake and use of the facilities. Part of the reason may be uncertainty over how to actually measure latrine use. Thus, the second objective is to evaluate and recommend approaches for assessing latrine use that can improve current methods. Finally, it seeks to advance our understanding of the patterns and determinants of latrine use in order to encourage and inform programmatic interventions that are correctly aimed at improving use as well as coverage.

The research comprised two phases, which included extensive pilot testing of the data collection instruments (Chapter 5) and the conduct of the final study (Chapter 6).

5 Piloting and research methods

This part describes the process that was undertaken to arrive at the final methods and tools to be used in the study.

Chapter 5 begins with a comprehensive review of potential latrine use assessment methods (Section 5.1; refer to Table 3-2). Details are then provided on the traditional methods which we adapted for use in this study (Section 5.2), a new device that allows for instrumented monitoring (Section 5.3) and the research undertaken to test and validate successive versions of this technology. I then describe our efforts to pilot and finalise these methods (Section 5.4).

Chapter 6 describes the methods ultimately used in the main research study. It also provides additional details concerning the study setting and population, sampling methods and enrolment, outcome assessment, data analysis and other methods.

5.1 Methods for assessing latrine use – an overview

The conventional methods to assess latrine use, also described in Section 3.3., include a range of qualitative and quantitative measures that may permit evaluation at an aggregated household level; at a semi-disaggregated level, for example, latrine use by demographic categories; or at a fully dis-aggregated level that examines individual level use (Coffey and Spears, 2014). These methods include structured observations, which have been extensively used to assess WASH behaviour; survey-based self-report measures; latrine spot-checks (also referred to as either latrine inspections or latrine use indicators in literature); latrine construction and functionality indicators; and qualitative measures that involve interviews with key informants; and ethnography. In addition, the past few years have witnessed a growing body of work that has used technology-based measures and instrumented monitoring in the WASH sector. While this section will not re-visit each of these measures in detail, the reader may refer to the comprehensive overview of the measures, including an examination of their strengths and weaknesses

(Table 3-2, included previously in Section 3.3). Based on this review, I will explain the rationale behind selecting some of these measures to assess latrine use in this research.

For the purpose of this research study, we used a mixed methods approach that enabled latrine use assessment at both individual and household levels and with potential applicability in large-scale assessments. The four main methods of latrine use assessment that were used in this study include: self- reported use by households; latrine spot-checks based on observable indicators of use; latrine construction and functionality indicators; and the Passive Latrine Use Monitoring (PLUM) device. Section 5.2 provides details of the three traditional methods of latrine use assessment employed in this study.

5.2 Methods of latrine use assessment: Reported use, latrine spot-checks, latrine construction and functionality indicators

5.2.1 Reported use

This method was survey-based and elicited data on latrine use both at household and individual levels. Household level queries included:

a. Whether any household members *ever use* the latrine(s). The response was binary: yes or no.
b. Whether any household members usually use any other latrines in the village. The response was binary: yes or no. This offered some data on potential shared sanitation practices in the village.
c. If the latrine is used more or less than usual at any time in the year. The response options included rains, summer (dry hot season), winter (dry cold season), same the year round or don't know. This potentially offered insight into reported variation in household level latrine use by season.
d. The reasons for non-use of latrines by household members who do not always use it. There were 13 response options that included, unfinished building, lack of privacy, prefer open defecation, for use by women only, among others. Respondents were permitted to select multiple responses, as relevant.

Individual level queries, that were either reported or self-reported and recorded accordingly, included:

a. For each member of the household, the name, age, gender and *usual* place of defecation (through the year) (WHO and UNICEF, 2006), where "usual" place of defecation included the following categories: latrine always (implying 100% latrine use), latrine usually (implying >50% use), latrine sometimes (implying <50% use), open defecation always, defecation in the household compound always, and others (specified).
b. Usual daily frequency of latrine use for household members who use the latrine.
c. For each member of the household, those who used the latrine for defecation "yesterday" and the approximate time of day they used it. Each reported 24 hour period was divided into four segments (Sunrise/Morning; Pre-Noon/Afternoon; Evening/Sunset; Night), and reported events were queried during each segment for each household member to aid more accurate recall. Visual aids depicting parts of the day and household members were used to facilitate understanding and recall, especially among illiterate respondents.
d. For each member of the household, those who used the latrine for defecation the "day-before yesterday" and the approximate time of day they used it. Similar to question c., each reported 24 hour period was divided into four segments (Sunrise/Morning; Pre-Noon/Afternoon; Evening/Sunset; Night), and reported events were queried during each segment for each household member to aid more accurate recall. Visual aids depicting parts of the day and household members were used to facilitate understanding and recall, especially among illiterate respondents.

5.2.2 Latrine spot-checks

Drawing from existing literature (Table 3-2), 13 latrine spot-check indicators were selected for assessing use in this study. The selection was driven mainly by the socio-cultural relevance of specific indicators and rural setting of the study (as assessed by pilot testing of the survey instrument: Section 5.4). The surveyors inspected each latrine for the following indicators: evidence that the latrine is used for storage; well-worn path to the latrine; wet floor; odour of stool/ urine; flies in latrine; discolouration of pan; presence or traces of faeces in pan; water container in/near the latrine; cleaning agents inside the latrine (e.g. broom, bleach etc.); slippers outside or inside the latrine; leaves/ dirt/ spider webs in the pan; water for hand-washing inside or near the latrine; soap/ ash for hand-washing inside or near the latrine. Outcomes for each indicator were binary, that is, either yes or no, corresponding to the presence or absence of the specific indicator. In addition, surveyors also observed and recorded the presence of human stools in the compound of each household by inspecting the premises.

5.2.3 Latrine construction and functionality indicators

The latrine construction and functionality indicators that were selected for this study were determined largely by the construction specifications defined by WaterAID (partly represented in Figure 6-2), the implementing partner for the TSC intervention in rural Puri district (Boisson et al., 2014). The premise was that completely constructed and functional latrines are more likely to be used by households than those that do not qualify as functional or where the construction is incomplete. The surveyors queried the households on the number of latrines they had and observed the type of latrine facility (for each latrine if a household had more than one latrine), which included the options of flush/pour flush latrine connected to a pit/ tank/ elsewhere, pit latrine with a slab, open pit latrine and others (specified). Respondents were also asked to estimate how long ago the latrine(s) was/were built. If a household had more than one latrine, the following latrine construction and functionality indicators were used to assess each latrine: the height of the latrine enclosure; the material of the latrine enclosure; presence of latrine closure or door over entry for privacy; type of latrine closure or door; presence of latrine roof; type of latrine roof; floor material around pan; pan condition and the number of pits per latrine. Observations or questions (if the pit was not visible) specific to the pit included the height of the pit in terms of the number of rings; pit covering; if the pit is uncovered, the reason for that and; the pan-pit pipe connection. The pit specific observations/ queries were repeated for additional pits, if any, connected to the latrine.

Certain assumptions were made in the selection of the above mentioned indicators. For example, a four foot high enclosure was considered to be the minimum height required to ensure privacy to an adult while squatting on the pan during latrine use. Therefore, the response options included no enclosure, an enclosure less than four feet, a four foot high enclosure; an enclosure of full height (defined as an enclosure that is adequately high to ensure than an adult's head is not visible while squatting) and others (specified). Similarly, as per WaterAid's guidelines (Boisson et al., 2014), the pit was supposed to have a minimum of three liner rings. The response options to this indicator therefore included: pit with less than three rings, pit with three rings or more; don't know (since the pits were sometimes buried and not directly visible), and others (specified). WaterAid guidelines also specified the installation of a Y-connector to provide for a second pit connection to the latrine and one connector pipe. This method included a repeat set of observations/queries for an additional pit, if it existed.

Overall, keeping these guidelines in mind and observing the variation in the quality of latrine construction by the six implementing non-governmental organisations (NGOs), the minimum criteria for latrine construction and functionality were pared down to include only: an unbroken/ unblocked toilet pan, a functional pan-pit connection, the presence of a pit (shared/ independent), and the presence of a pit covering. These criteria were also used to define eligibility of households in the study (Chapter 6).

5.3 Instrumented monitoring: Passive Latrine Use Monitoring (PLUM)

5.3.1 The PLUM device hardware

This research used a variation of the "Passive Latrine Use Monitoring" (PLUM) device that was jointly developed by the London School of Hygiene and Tropical Medicine (LSHTM) and the University of California, Berkeley, USA (UCB) (Clasen et al., 2012b). It is a smart device with the potential to provide an accurate round-the-clock measurement of latrine use. It uses a passive infrared (PIR) motion sensor to detect the presence or absence of a person within its viewing range. It can be fixed within the latrine super-structure, either on a wall that does not face a door or on the roof, if one exists, as long as the subject is within range (Figure 5-1) (Subramanian and Taneja, 24 August, 2011). The PLUM is designed to be weather resistant, battery powered, easily installed and removed, acceptable to households (HHs) and relatively low in cost to permit its use in a research study. As described below, there were various generations of the device that were tested and modified based on results from testing.

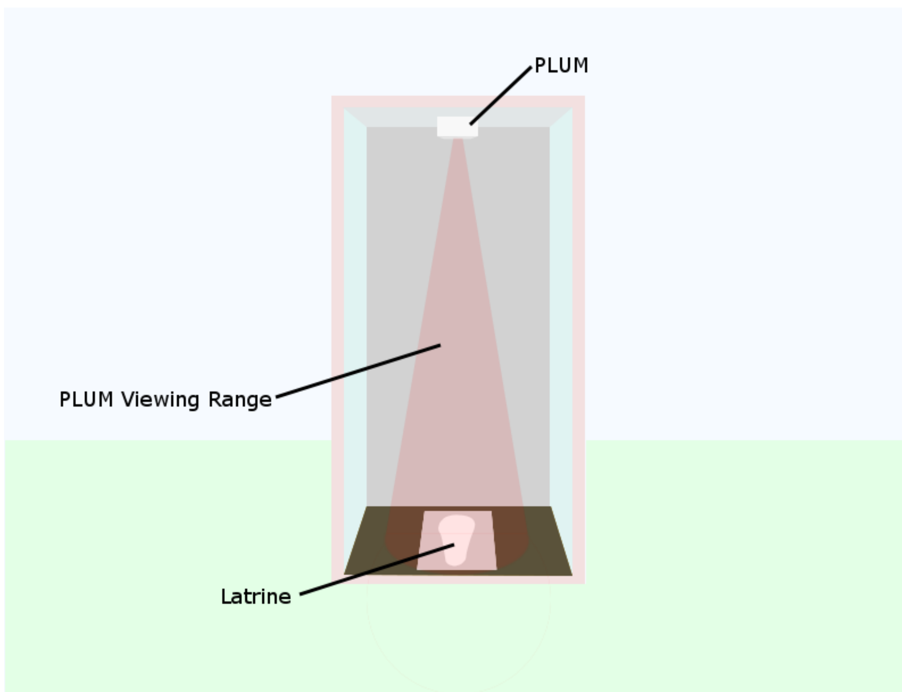

Figure 5-1: The viewing range of the PLUM sensor (Taneja, J, UCB)

5.3.1.1 The “second generation” (2G) PLUM

The first generation (1G) PLUM was developed in the laboratory and was designed as a prototype. The first production version was the second generation device and is referred to as the “2G PLUM”. Both the 1G and 2G PLUMs were constructed from off-the-shelf parts, which include a PIR sensor, an Arduino Pro Mini microcontroller for computation, a microSD card for data storage and 3 AA batteries to power the device (Figure 5-2). The unit was enclosed in a 9cm x 9cm x 6cm watertight plastic housing with an aperture for the sensor to capture motion within its viewing range. The aperture was covered by a thin plastic film that enabled the infra-red radiation to pass through the sensor yet making it invisible to householders and also shielding it from dust and insects (Clasen et al., 2012b).

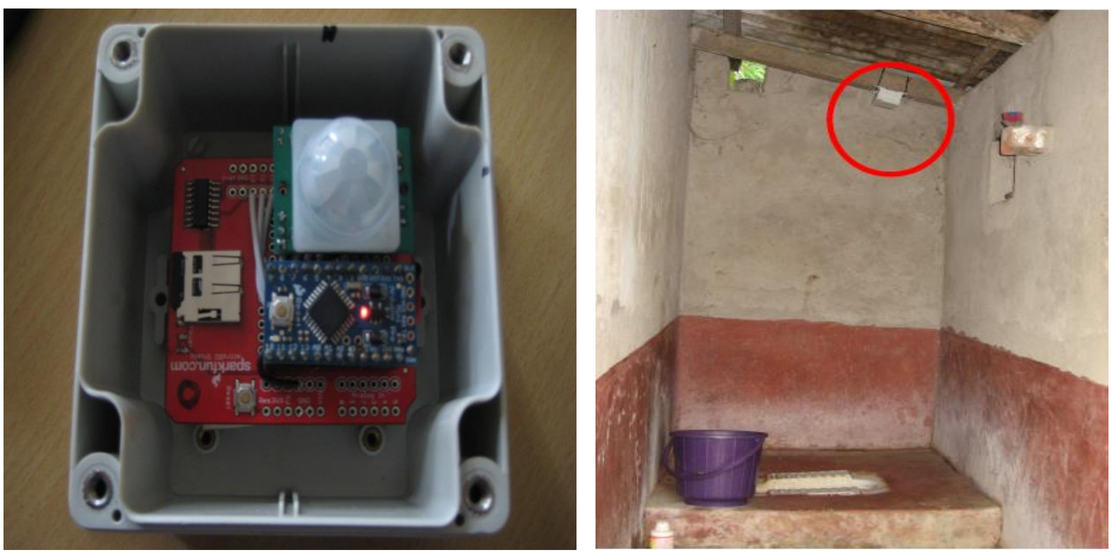

Figure 5-2: Inside view of the 2G PLUM device and an example of how it was installed in a latrine

The 2G PLUM device was pilot tested over five weeks where 132 households were monitored for eight days each in Odisha, India, in 2010 (Clasen et al., 2012b). In addition to testing the equipment in a natural setting, results from the pilot also informed the development of an algorithm that could be used to interpret and analyse PLUM signals. Further, a comparison of usage event signals of the PLUM with recordings from structured observations, served to calibrate output from the device. The PLUM was found to record events relatively accurately, with the added benefit of presenting an extended perspective that is challenging to characterise with structured observation. It also offered the advantage of relatively easily accessible and analysable data. Significantly, there is also evidence that the PLUM reduced reactivity (Hawthorne Effect) that was associated with direct observation of latrine visits, the considered "gold standard" for assessing latrine use (Clasen et al., 2012b).

However, the 2G PLUM had certain limitations. Among other things, it had a battery-life of only two weeks, effectively limiting the installation period to seven to ten days. In addition, the pilot testing revealed that the PLUM algorithm developed by UCB, which uses a minimum event separation time of three minutes, tends to result in systematic under-counting of events during peak traffic periods where the inter-arrival time may be less than three minutes. Lastly, it only captures likely defecation events ascertained by the algorithm, allowing for potential error in the process (Clasen et al., 2012b).

5.3.1.2 The "third generation" (3G) PLUM

The 3G device, which was used in this research between July 2011 and February 2012, was designed as a more advanced version of the 2G with certain structural and technological modifications to its features (Figures 5-3, 5-4 and 5-5). For example, a toggle power switch was added to the housing cover in an attempt to extend the battery-life of the device. The battery-life of the 3G device was intended to be three months. Further, an on-board clock that provided an actual time-stamp of the occurrence of an event was added. In addition, this device had a flash storage capacity and transmitted regular updates about its status at a specific frequency band at the rate of once every two minutes. These updates could be received by any compatible paired "TelosB mote" (communication device) plugged into the USB port of a netbook computer running the PLUM software. The TelosB mote was able to communicate with the PLUM nodes by listening for status updates and initiating data downloads from the PLUM to the computer. The data was formatted as a .CSV file (comma-separated value file). Once downloaded, data was stored in the local file system in the PLUM 'Dropbox' folder, a cloud-based file storage system. The processing and analysis of the raw PLUM data into "latrine/likely defecation events" per the UCB algorithm was done by uploading the data on a website created by UCB (http://plum.cs.berkeley.edu/plumweb2/process/upload) (Subramanian and Taneja, 24 August, 2011).

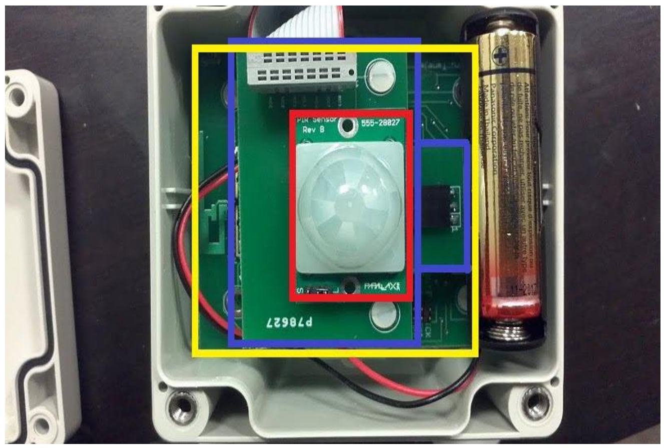

Figure 5-3: The internal fitting of the 3G PLUM. The yellow outline shows the main board; the blue outline shows the secondary sensor board; the red outline shows the PIR sensor (covered with a domed "Fresnel" lens for protection and optical filtering) (Photograph: Taneja, J, UCB)

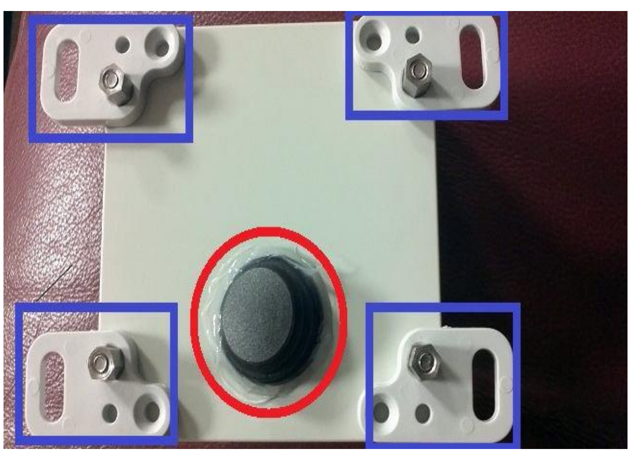

Figure 5-4: The PLUM mounting side – the red outline shows the power toggle switch; the blue outlines show the four 'feet' for mounting the PLUM (Photograph: Taneja, J, UCB)

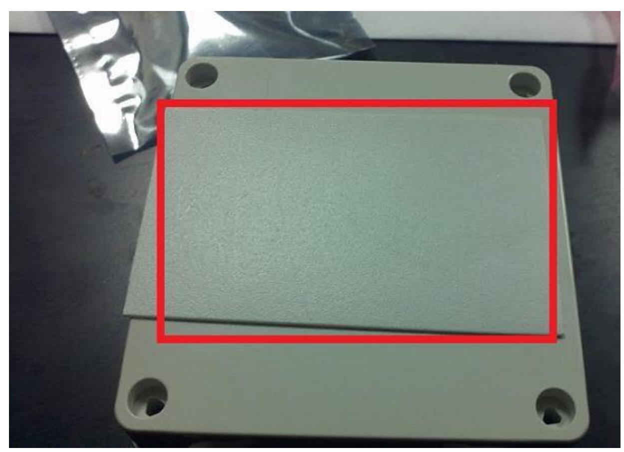

Figure 5-5: PLUM lid – the red outline shows the screen cover for the sensor (Photograph: Taneja, J, UCB)

The 3G device was pilot tested for this study in December 2011-February 2012. The details of the pilot testing are included in Section 5.4.

5.3.1.3 The SweetSense (SS) PLUM

The plan was to rely primarily on the 3G PLUM for this research. However, extensive work in the laboratory and field revealed significant problems with the robustness of the 3G and the manner in which it uploaded data. By April 2012, we identified an alternative device that could be fitted with the PLUM sensor package and used with the signal interpretation algorithm developed in connection with the 2G and 3G devices. This platform, known as the SweetSense (SS) PLUM (Figure 5-6), was developed in collaboration with the Sanitation, Water, Environment and Energy Technologies Laboratory (SWEETLab), an affiliate of Portland State University in the United States (www.pdx.edu/sweetlab). It is described in greater technical detail in other publications (Thomas et al., 2013a).

Figure 5-6: The SweetSense (SS) PLUM - an external and internal view of the final version used in the study

Briefly, the data logging technology combines commercially available front-end sensors, selected for specific applications including water treatment, cookstove, sanitation, infrastructure or other applications, with a comparator circuit board that samples these sensors at a reasonably high rate (www.pdx.edu/sweetlab). The comparator boards monitor the sensors for trigger threshold events that start and end periodic local data logging. In this case, a simple infrared motion detector was used, identical to the commercial sensor selected in the 2G (Clasen et al., 2012b) and 3G PLUMs (http://www.parallax.com/product/555-28027). The comparator circuit was linked with the motion detector, and recorded each detected motion. The motion detector has a three second logging window, while the data logger recorded in ten second "buckets". Therefore, as many as four motion conditions may be logged by the system every ten seconds. The logger records the precise date and time of the motion "bucket" referencing Unix time obtained from an internet server, and adjusted by the time zone in India (www.pdx.edu/sweetlab).

One or more times per day, the comparator board relays logged data events to the internet via Global System for Mobile Communication (GSM) cellular phone technology. Data is recorded for each sensor, as identified by its "MAC address", a hardware chip unique to each board. Data processing is enabled on an internet based software program utilizing C++ and R, where the primary algorithms are stored (www.pdx.edu/sweetlab). The board also contains a micro-SD card for local logging of all data, both as a backup and in environments where cellular data service is not available, which was frequent in this study.

The online software system contains several data correction, reduction and analysis routines (www.pdx.edu/sweetlab). With a C++ routine, data is validated through examining for expected reporting patterns, and corrupted data is discounted. A MySQL table of valid raw data is appended for each sensor, at each reporting interval. In the case of SD card based data, this data is uploaded via an online webpage. The C++ routine cross-checks any uploaded data against existing data, to eliminate duplicate data.

Subsequently, a R code is run to interpret the raw data and generate estimates of "latrine/likely defecation events" (www.pdx.edu/sweetlab). The algorithm employed is largely based on 2G and 3G PLUMs, with some adjustments to account for technological differences between the sensors.

Finally, the hardware platform is powered with five AA batteries to provide a 6-18 month lifetime while still achieving a high sampling rate of up to 8 hertz. Battery life is saved through triggered event logging and infrequent reporting (www.pdx.edu/sweetlab).

The device platform was also originally to be fitted with a magnetic door switch (Figure 5-15), so that in addition to detecting motion within the latrine superstructure, door activity could also be recorded. The rationale for including this was that it could serve as a useful backup for (and validation of the method of interpreting) the signal from the pyro-electric cell. However, the absence of doors or use of broken doors in some latrines could potentially hinder the effective use of the door monitor. Additionally, the possibility of tampering with the connection between the two modules, i.e., the latrine motion detector and the door switch, also presented a potential limitation. It was decided that these aspects would be scrutinised in the pilot testing along with other findings that may emerge in the process.

5.3.2 PLUM output and signal interpretation

5.3.2.1 The 2G and 3G PLUM

Both the 2G and 3G PLUMs record binary data in terms of one-dimensional timestamps where a change in the background infrared profile indicates that movement occurs. It is measured in milliseconds since initialisation. This data is downloaded and imported into MATLAB (MathWorks) for analysis (Subramanian and Taneja, 24 August, 2011).

The interpretation of the PLUM signals to enable conversion into latrine events is determined by an algorithm developed by UCB. The development of the timing parameters have been informed by a combination of laboratory and field experiments for calibration and validation (Clasen et al., 2012b). They are explained in the following steps:

- Step 1: Raw PLUM data is captured in triggers (with a binary output of either 1 or 0) when motion occurs. Triggers that occur within 15 seconds of each other are lumped together into "edges", implying latrine entry or exit. If a trigger does not have a neighbouring trigger, either 15 seconds before or after, it is considered noise or non-latrine event triggering and is rejected. The selection of 15 seconds is based on empirical test results on latrine use activity – where dense triggering is associated with latrine entry movement, relatively little or no triggering is observed during the squatting phase, followed once again by dense triggering again during the anal cleansing and latrine exit phase.

- Step 2: This step aims to combine all edges associated with a single latrine use into an "activity". All edges that occur within ten minutes of the beginning of the previous edge are lumped together. Edges that are shorter than 30 seconds and have no other edges either 10 minutes before or after are rejected as noise or non-latrine events.

- Step 3: Activities that are longer than six minutes are reviewed. If a given activity period has no edges for at least three minutes, the activity is split at such time points and broken into additional activities. However, this step may result in systematic under-counting of events during peak traffic periods where the inter-arrival time may be less than three minutes (Clasen et al., 2012b).

As the mechanism for processing PLUM data for the Sanitation Trial was in the process of being finalised by the UCB team, an algorithm, similar to the UCB version, was developed by LSHTM (Schmidt, W.P, February 2012) to interpret the PLUM signals using STATA, Version 10, as part of a pilot in December 2011-January 2012 and to help with sample size calculations for PLUM deployment in this research. It may be noted that the final responsibility of processing the raw PLUM data reverted to UCB, as originally planned.

5.3.2.2 The SweetSense PLUM

The algorithm employed is largely based on that developed by UCB (Clasen et al., 2012b). Certain adjustments were made to account for technological differences between the sensors. To validate the adjusted interpretation algorithm, the researcher deployed the SweetSense technology alongside the earlier, validated technology (2G) for one week each in 11 household latrines in Bhoigun, a village in Odisha in August 2012. As per protocol, selected latrines had to be independent of bathing areas and the two PLUM units for comparison were placed alongside each other to the extent possible to minimise errors. A secondary data source was also used consisting of structured observations, where an observer manually recorded use of each latrine for five hours per day in each of the 11 households. The sample could not be larger as the number of functional 2G units was limited and deployment therefore needed to be rotated across the households.

The analysis of the validation data was undertaken by SweetSense Labs to enable any resulting latrine use algorithm adjustments, if necessary. In order to assess agreement between the two measures, the 2G PLUM and the SS PLUM, a Bland Altman plot was generated (Figure 5-7), which is commonly used to compare methods of measurement of the same parameter (Bland and Altman, 1986, Bland and Altman, 1999). In this approach, the difference between the measurements by the two measures is plotted against the average of both measures. This enables an assessment of whether the difference between the measures (bias) is related to the magnitude of the measurement. It may be observed from Figure 5-7 that the mean difference between 2G and SS PLUMs usage events was 2.3 events per household per day, as represented by the solid horizontal line in the scatter plot. The comparison indicated agreement, on average, between the two technologies, but with a large standard deviation of approximately eight latrine use events per household per day (O'Reilly et al., 2015). It was therefore decided that the third comparative method of structured observations was essential to have confidence in the comparability of these two technologies.

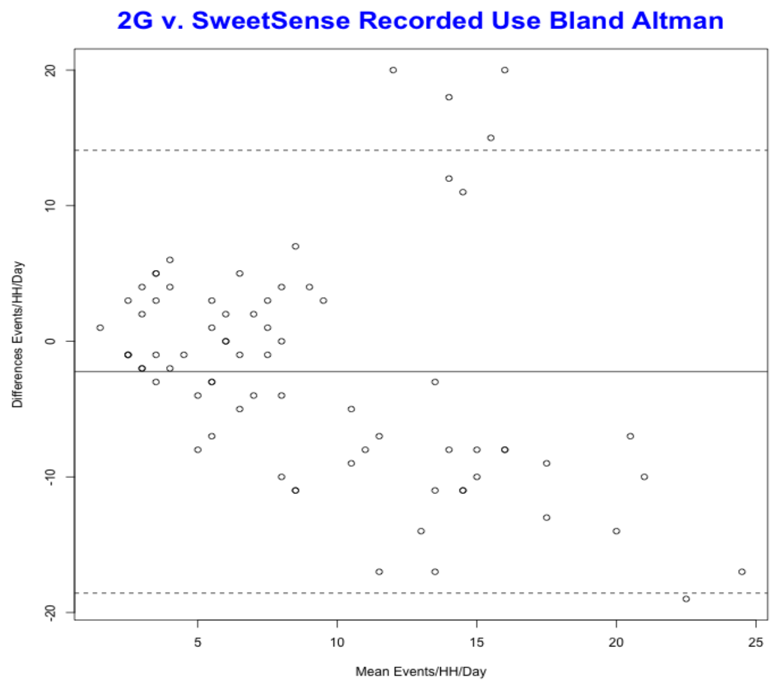

Figure 5-7: Bland Altman plot of the difference against the average to compare the 2G PLUM and the SweetSense PLUM methods of measurement (O'Reilly et al., 2015)

In the output analysis of SS PLUM versus structured observation (Figure 5-8), the following steps were undertaken: first, each sensor-detected event was compared against the temporally nearest observed event, allowing for an evaluation of error associated with over-reporting events, or false positives (red scatter plot and associated line fit). Next, the converse was applied, comparing each observed event against the temporally nearest sensor-event, indicating error associated with under-reporting, or false negatives (blue scatter plot and associated line fit). The axes are shown in Unix seconds (seconds since 1 January, 1970) for ease of computational analysis. The analysis shows good agreement between the observed and sensor-detected events, with only three outliers. Two (red) show observed events that were not closely aligned with sensor events. One (blue) is the converse. The sample size of the observed versus recorded events are different because the sensors were in place in the latrines for considerably longer than the monitoring period of the observers, leading to a greater number of sensor events available for the correlation analysis. These results suggest that the latest generation of PLUM sensors interpret "use events" in a method substantially similar to the earlier, validated, technology (O'Reilly et al., 2015).

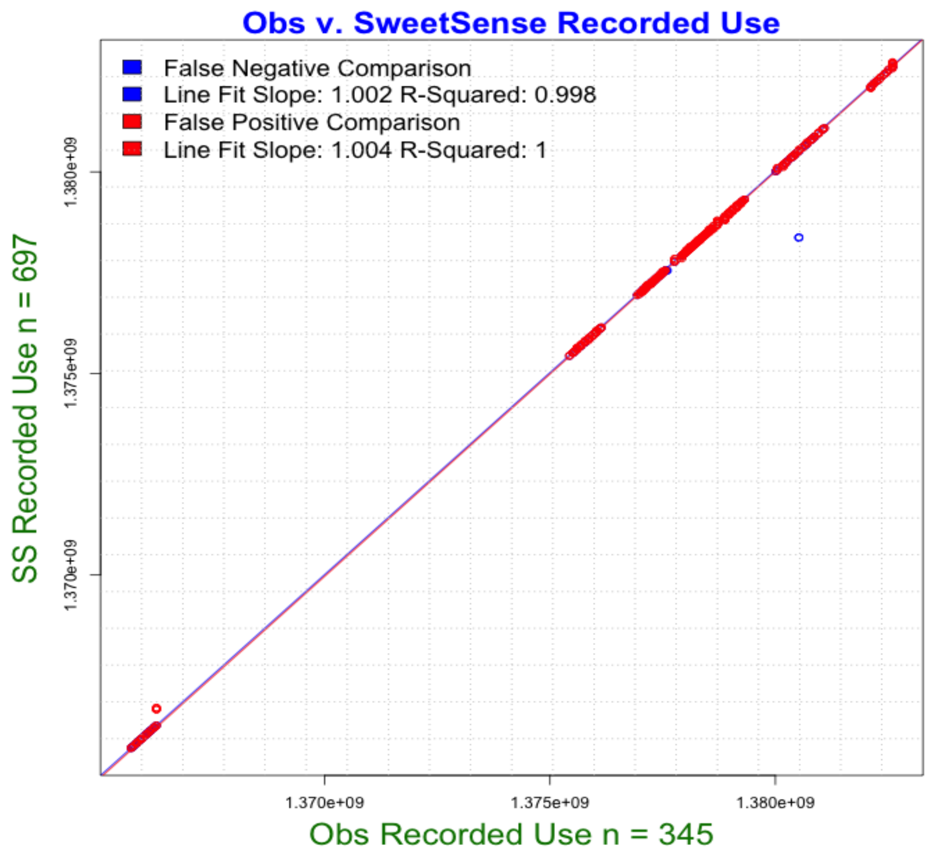

Figure 5-8: Structured observations (Obs) versus SweetSense PLUMs (SS) recorded latrine use (O'Reilly et al., 2015)

5.4 Pilot testing

This section includes details of all the pilot testing and research that was conducted with various generations of the PLUM and other latrine use assessment measures for this study. Overall, it was divided into two phases of pilot testing. Phase one included the pilot testing that was undertaken between August 2011 – February 2012 for the 3G

PLUM and survey-based methods to assess latrine use. Phase two corresponds to the pilot testing conducted for the SweetSense PLUM and additional testing on the three survey-based methods to assess latrine use from June 2012 – September 2012. Figure 5-9 graphically displays the timelines for Phases one and two to aid clarity.

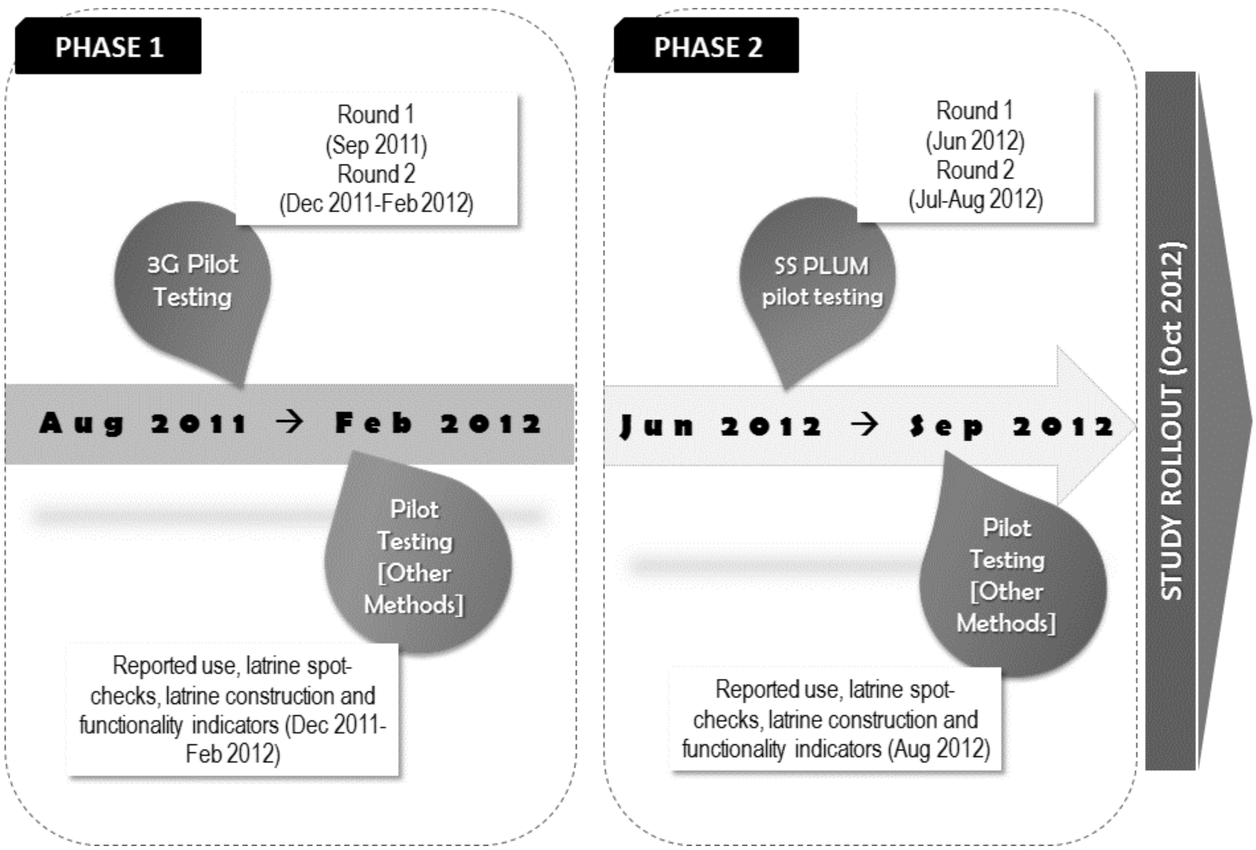

Figure 5-9: Timeline of pilot studies undertaken between August 2011 and September 2012

5.4.1Phase 1 preparation and pilot testing (August 2011 to February 2012): 3G PLUM and other methods to assess latrine use

This section describes the pilot testing as it was undertaken in the field. The first section (5.4.1.1) includes the orientation and training that was provided to the enumerators prior to the initiation of the project. The next section (5.4.1.2) describes the pilot testing of the 3G PLUM that was conducted in two rounds. Round 1 involved small scale testing conducted in a controlled field setting. In Round 2, the 3G device was tested in the field on a larger scale and has therefore been described in detail in terms of the testing objectives, methods used, results obtained, discussion and key learning. The third section (5.4.1.3) describes the pilot testing conducted for the additional measures of assessing latrine use – reported use, latrine spot-checks and latrine construction and functionality indicators. The last section (5.4.1.4) refers to the process for estimating a "defecation frequency standard" for the study population based on reported defecation frequency by a sample and literature-based evidence.

5.4.1.1 Training of enumerators

In August 2011, the enumerators that were involved in the pilot participated in orientation training for the latrine use assessment study. They were explained the broad objectives and rationale of the study. They were introduced to the range of latrine use methods that would be employed in the study. Next, they were explained the pilot testing process that would precede the study. The remaining orientation was conducted in three parts. Part 1 of the training addressed relevant study implementation aspects, including the protocol to be followed; rapport formation with household members; obtaining consent; and responses to frequently asked questions. Part 2 focused on one, of four, latrine use assessment methods, the 3G PLUM device. This part involved a combination of theoretical and practical sessions to facilitate understanding. The enumerators were oriented to the functioning of the PLUM device, data output processes and formats, and device checking. They were also trained on the installation protocol to be followed in the field. Practice sessions were included on the correct placement of the device in the latrine during installation to ensure that the quality of data was not compromised. The following aspects were emphasised in this regard:

- The device must not face the latrine door/ entry or a window to avoid recording ambient movement outside the latrine. The viewing range of the sensor must capture the latrine pan to enable recording of activity in that zone (as shown in Figure 5-1).
- The device should be securely attached to the wall or roof so that it cannot slide into any other position and to prevent tampering by household members.
- The device should not be covered.
- The device should be placed in a position that is unlikely to get drenched by water, especially during latrine cleaning when buckets of water are poured over the platform and pan.

Part 3 of the training addressed the remaining three methods of latrine use assessment to be used in the study. The rationale behind each of these methods was explained. The researcher also reviewed all the questions/indicators in each of the three tools with the team and described the pilot testing process that would be undertaken prior to finalisation of the tools.

5.4.1.2 Testing of the 3G PLUM

The 3G PLUMs were delivered to Bhubaneswar, Odisha, in August 2011, whereupon we worked with the UCB staff for two weeks to confirm operation and use. During this time, we identified several devices and USB motes (to facilitate communication with an installed PLUM unit and wireless data downloading, as mentioned in Section 5.3.1.2) that were not fully functioning. Considerable time was spent in the subsequent months to resolve these hardware issues.

At the same time, the modifications made to the 3G device (as mentioned in Section 5.3.1.2) made it imperative to pilot test the product and the procedures involved in the field. The process is described below.

5.4.1.2.1 Pilot testing of 3G PLUM: Round 1

The device was initially tested in a small-scale controlled field setting. The 3G PLUM was installed in ten households in a slum settlement in Bhubaneswar for a total of nine days in September 2011 during the rainy season. Informed consent was obtained from all the participating households prior to installation. The first round of testing exposed both hardware and software issues with the device. The main issues are mentioned below:

- One device had been removed by the household.
- Four of the remaining nine devices that were still installed were not getting detected by the USB mote to facilitate checking and wireless data downloading.
- Four out of ten devices were found switched 'OFF' indicating that the toggle switch may have been tampered with, making the device non-functional.
- The range for device detection and data downloading was found to vary between devices. In some instances, the device was getting detected at ten feet. In other cases, detection was only taking place in close proximity to the device, such as at the entrance to the latrine.
- Water-proofing of the device needed to be strengthened.
- The USB TelosB mote required some protective water-proof cover yet communication with the device was challenging when the USB was concealed in plastic.

These issues were communicated to the UCB product development team who, with inputs from LSHTM, made necessary modifications to address major concerns. In summary, the key modifications included covering the toggle switch with a plastic cap just prior to deployment to minimise the risk of tampering by the householders; re-programming the USB mote to ensure greater compatibility with the PLUM device programming; and water-proofing of the PLUMs to prevent water leakage into the device.

5.4.1.2.2 Pilot testing of 3G PLUM: Round 2

5.4.1.2.2.1 Objectives:

The objectives of this round of testing conducted in December 2011 - February 2012 were to: (a) determine the acceptability of the PLUM to households with latrines; (b) finalise the protocol for installation and removal of the device across varied latrine settings; (c) assess the effectiveness of the device in detecting movement in and use of the latrine; (d) assess the process of data recording, downloading and analysis; (e) estimate the sample size for the study and the period for which the PLUM should be installed per household.

5.4.1.2.2.2 Methods:

The pilot was conducted in the context of the Sanitation Trial study population with a focus on intervention surveillance households (ISHHs) that were sampled from among the 50 intervention villages in the Sanitation Trial. ISHHs were considered eligible if they had a completely constructed and functional latrine (per WaterAid's guidelines: Section 5.2.3) as a result of the TSC. This was determined by observation and latrine inspection. Since latrine construction status was a key factor to be considered, a village selection criterion was applied to ease logistical challenges. Only villages that had at least three or more households with completely constructed and functional latrines were included in the pilot testing round. 150 randomly sampled (using a computer generated sequence from a list of eligible households) ISHHs from 38 intervention villages were enrolled in this pilot after taking consent from each of the participating households. While seeking consent, an effort was made to explain that the device did not capture any images but only recorded numerical data (for example, similar to how an electricity meter measures electricity consumption). The 3G PLUM was installed for an eight week period. One round of checking at approximately two weeks after installation was included to ensure that the device was working.

5.4.1.2.2.3 Results:

A total of 157 3G PLUMs were deployed in 150 ISHHs across 38 intervention villages (some HHs had more than one latrine and each was fitted with a PLUM). In the checking round, 29 devices were replaced – taking the total number deployed to 186. With reference to the specific objectives of the pilot testing, the findings were:

(a) PLUM acceptability: 215 ISHHs were approached of which 64 did not have completely constructed and functional latrines. 150 ISHHs readily consented to installation of the device in their latrines after initial explanations. One household did not consent to install the PLUM in the latrine as the concerned person was an elderly male member of the household who did not have any other family members present at the time that we approached him. It may be inferred that acceptability of the PLUM device within the study population was high. It also appeared to be dependent on the ability of the researchers to answer questions competently, especially those raised by female family members, and transparency about the data output from the device.

(b) PLUM installation and removal protocol: A device installation protocol was developed and refined based on learning from this pilot (Figure 5-10). It was observed that latrine settings and the quality of superstructures varied considerably, including latrines with no roofs, thatched or makeshift roofs made with leaves, latrine enclosures made with sacks, as well as solid brick and cement units with considerable variation in height. In addition, the presence of a door was not a consistent feature across all latrines. Thus, the placement of the PLUM varied depending on the quality and condition of the super-structure. In several cases, the device was drilled into the masonry to ensure that it was firmly in place so that the sensory aperture could retain focus on the pan in the latrine yet avoid getting soaked when the latrine was washed with buckets of water.

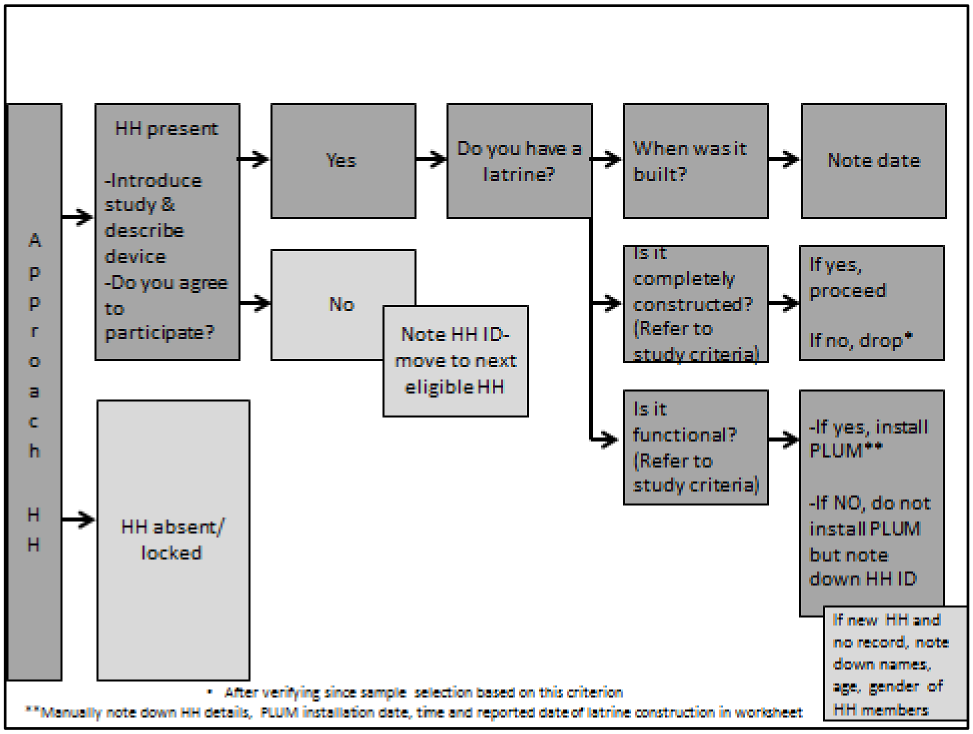

Figure 5-10: 3G PLUM installation protocol

(c) Effectiveness of the 3G PLUM in detecting movement in and use of a latrine - the findings are as follows:

First, among the 186 3G PLUMs (including replacements) that were deployed in the pilot in December 2011 - February 2012, there was hardware and software failure in approximately 56% of the devices. This resulted in either the data not getting recorded or the downloading mechanism not working. In 40 PLUMs, 75% recorded data for 50% or less of the total observation period. Among the remaining PLUMs, recordings from 30 ISHHs were selected for analysis where there was reasonably good quality continuous data for a minimum of 15 observation days (Table 5-1). The researcher noted that device failure was not found to be related to any specific latrine or household characteristics.

Table 5-1: Data from 30 intervention surveillance households where the 3G PLUM was installed during Round 2 of the pilot testing (December 2011 - February 2012)

No. of HH	HH ID	PLUM ID	Total obs. days	Total PLUM-based events	No. of HH members	Average no. of PLUM events/ person/ HH/ day
1	401032	23	49	13	8	0.03
2	401044	216	18	13	10	0.07
3	404069	261	15	9	9	0.07
4	408061	287	48	108	8	0.28
5	408012	3	49	91	6	0.31
6	613051	281	50	21	4	0.11
7	613079	177	31	16	8	0.06
8	632113	284	30	80	4	0.67
9	632139	79	28	31	6	0.18
10	301063	215	45	54	7	0.17
11	302017	219	44	58	8	0.16
12	309134	108	47	86	6	0.30
13	211042	268	60	84	23	0.06
14	205052	140	30	11	5	0.07
15	221144	114	47	125	6	0.44
16	221061	59	39	3	7	0.01
17	221137	29	21	15	7	0.10
18	201014	186	29	11	7	0.05
19	115110	279	40	63	7	0.23
20	109096	126	25	11	11	0.04
21	505062	83	49	63	5	0.26
22	505104	193	58	77	4	0.33
23	502019	172	60	152	10	0.25
24	502066	122	57	94	8	0.21
25	502047	278	59	135	6	0.38
26	628059	87	53	38	6	0.12
27	618023	64	48	68	5	0.28
28	620025	127	41	12	6	0.05
29	620022	89	41	21	10	0.05
30	502065	90	45	29	7	0.09

Second, at the time it was unclear whether the lack of a signal meant that the latrine was not being used or that the device was not operational. The battery voltage of the device was designed to drop to zero in the event of a device mal-function. However, this phenomenon was not observed in any of the PLUM devices where data was downloaded and there were gaps in the recordings.

Third, data recordings from 30 ISHHs for a minimum of 15 days to a maximum of 60 days from 38 intervention villages enabled preliminary exploration of patterns of use, both between households and within households. For example, for each household, the mean PLUM-based latrine events per person per household per day were calculated. A comparison of the means from all 30 ISHHs provided preliminary understanding of the extent of variation between households with regard to latrine use (refer to Figure 5-11).

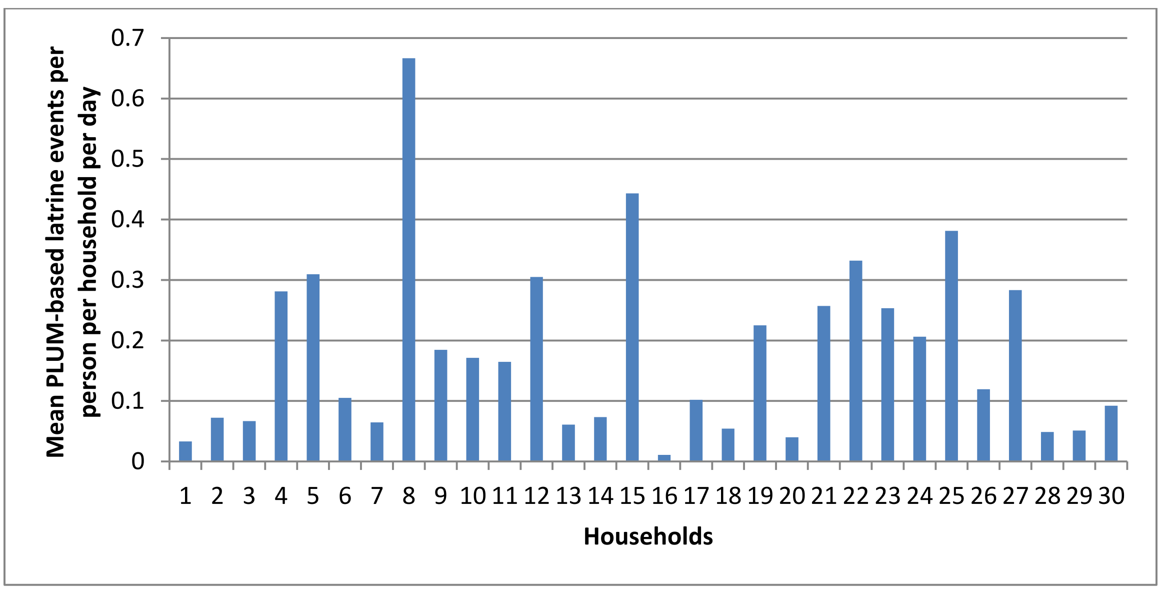

Figure 5-11: Variation between 30 ISHHs of mean PLUM-based latrine events per person per HH per day as recorded by the 3G PLUM

Fourth, the 3G PLUM recordings from 30 households also enabled observation of patterns of latrine use within households over a 24 hour period. Examples of PLUM-based latrine event recordings by hour over the observation period reveal potential patterns in latrine use based on time of day. For example, Figure 5-12 for a given household reveals two peaks in latrine use between approximately 0430hr to 0630hr and between 1430hr and 1630hr. Similarly, the pattern observed in Figure 5-13 shows that the highest percentage of (PLUM-based) latrine events in that particular household takes place 0530hr to 0630hr for the given time period.

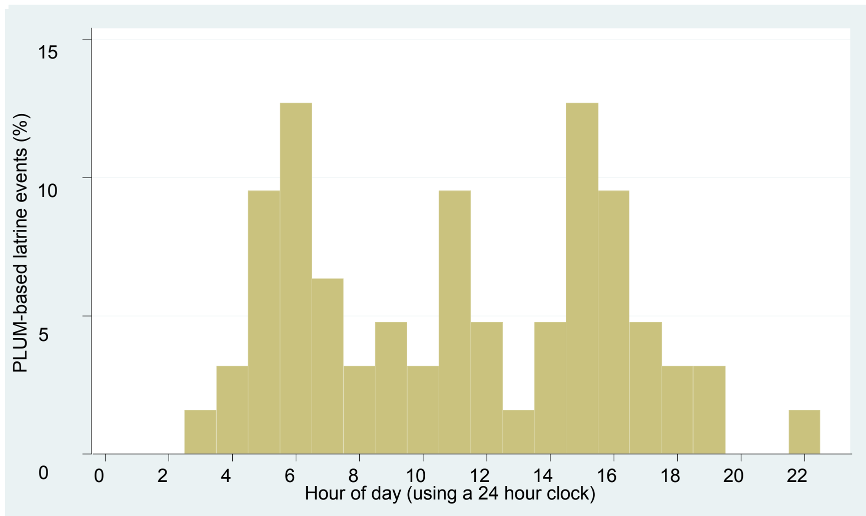

Figure 5-12: An example showing the pattern of PLUM-based latrine event recordings by hour, using a 24 hour clock, for a given household over the observation period

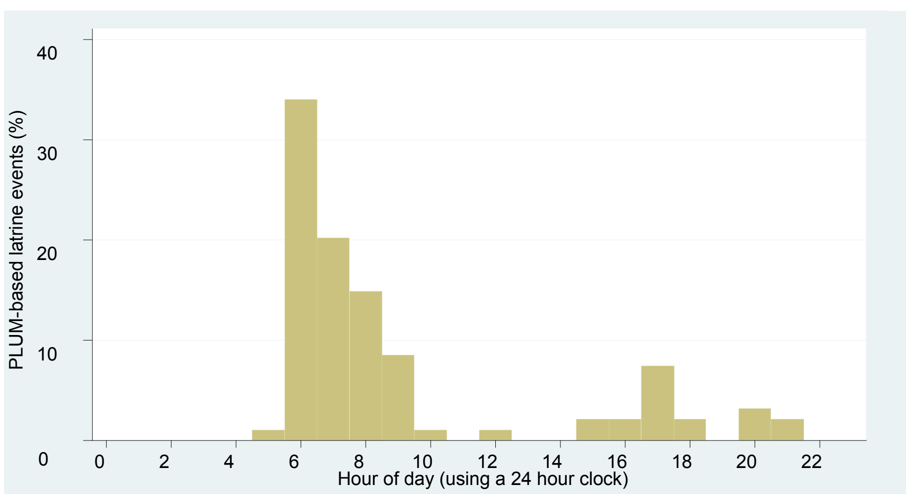

Figure 5-13: An example showing the pattern of PLUM-based latrine event recordings by hour, using a 24 hour clock, for a given household over the observation period

(d) The process of data recording, downloading and analysis: This aspect notably required additional work. The hardware and software issues referred to previously had implications on the recording and downloading capabilities of the 3G device. In addition, the website for processing and analysing the PLUM-based data was still being finalised. Detailed feedback was provided to the UCB team on learning from this round of pilot-testing.

(e) At the time, sample size calculations for the study were done based on data obtained from 30 households where the devices did not fail during the pilot testing. Since device failure was not linked to any specific latrine or household characteristic, these 30 households were considered representative. Additionally, the duration for which the PLUM should be installed per household was also calculated based on data from these households (Section 6.3.2).

It may be pertinent to mention here that the sample size calculation in the final study, in which a different generation of the device, the SweetSense PLUM, was used ultimately, was also determined by logistical reasons, that is, the number of available PLUM units. However, the PLUM-based observation period per household remained unchanged from the estimate based on the Round 2 pilot data.

5.4.1.2.2.4 Conclusions:

Although the 3G devices could potentially record valuable round-the-clock data on latrine use, as is evident in the data obtained from the recordings of 30 3G PLUMs, the overall functioning of the device appeared to be un-reliable. While UCB continued to work on these issues, we elected to design the study around the use of the SweetSense PLUM, subject to satisfactory performance in a pilot designed for the summer of 2012.

5.4.1.3 Piloting of additional methods of latrine use assessment: reported use, latrine spot-checks, latrine construction and functional indicators of use

As part of the PLUM pilot, we developed and piloted three additional measures of latrine use based on previous research (described in Chapter 3, Section 3.3 and in Table 3-2). These additional survey-based measures, which included reported latrine use, spot-checks of latrines and observations of latrine construction and functionality, were designed to be minimally intrusive and to be potentially compatible with the deployment of the PLUM.

5.4.1.3.1 Objective

The survey-based methods to assess latrine use were pilot tested to assess the validity, practicality and socio-cultural relevance of the indicators comprising each of the three measures of latrine use.

5.4.1.3.2 Methods

At the time of this pilot test, the survey-based measures of latrine use comprised indicators that included the following:

- Observations of the construction status and functionality of the latrine. The main indicators were based on WaterAid's minimum requirements for latrine construction, which in turn were drawn from the TSC: the presence of a wall that is at least five feet in height, the presence of a door, the condition of the pan and foundation floor (to ensure that they were not damaged as a result of flooding in the region in 2011), an assembled pit with at least 3 liner rings, (correct) connection of pipe to pit, and the presence of a pit cover. There were a total of 29 indicators that were tested with a view to narrowing the list to only those that were valid, practical and efficient to observe.

- Spot-checks of the latrines were also undertaken to assess, at an indicative household level only, whether the latrines were being used. Of a total of 15 indicators, the main ones were a well-worn path to the latrine, presence of cleansing materials inside or near the latrine, wetness of the slab or latrine floor, dis-colouration of pan, and the presence of odour and faeces. The pilot testing of these indicators was aimed toward retention of those indicators that appeared to be easily and efficiently observable and valid in the cultural and rural context.

- Reported latrine use. This module comprised two parts. The first component gathered general data on, for example, “usual place of defecation” for each family member, reasons for non-use, reported variation in use by season, if any. The second component aimed to assess latrine use for each member of a household over a two day recall period (“yesterday” and the “day before yesterday”) broken into four segments per day. The primary objective of the second component was to potentially compare the obtained data with latrine event recordings from the PLUM device in the same period. Reported use data may also offer additional insights, which may not be captured by any of the other methods, such as the gender profile of latrine users.

The pilot testing of these tools was conducted simultaneously with the Round 2 testing of the 3G PLUM (Section 5.4.1.2.2). The same 150 ISHHs that were enrolled in the 3G PLUM testing were also used to pilot test the survey-based measures. The latrine construction and functionality and latrine spot-check measures were conducted at the first visit to the household, which was also when the PLUM was installed in the household latrines. All the questions of the reported latrine use measure, except for the section that covered reported use over a two day recall period, were also conducted during the first visit to the household. The household was queried on the two day recall period during the second visit to the household after two weeks when we had to check the status of the PLUM.

5.4.1.3.3 Results

The results mentioned below have also been summarised in Table 5-2.

a) Determining the construction status and functionality of the latrine. The latrines in all 150 ISHHs where the PLUMs were installed met these criteria broadly, albeit with variations in the super-structure, depending on the NGO responsible for latrine construction in the Block. This implied that the relevant indicators in this module of the survey would need to be modified to account for such variations, as opposed to strictly adhering to the WaterAid-TSC specifications. For example, the height of the latrine enclosure was modified from five feet to options that included no enclosure, less than four foot enclosure, four foot enclosure, and full height of the enclosure. Similarly, the material of the enclosure was broadened to include cloth/ plastic/ sack, bamboo/ coconut mat, plastered brick with tiles, among others. Given the observed variations in the type of latrine closure or door, this indicator was also modified to range from cloth/ plastic/ sack to metal sheet. All the observed latrines did not have a roof and some had partial temporary roofs in an attempt to cover the toilet pan. It was noted that three households reported using latrines that did not have a door/ closure over the entrance or an enclosure/ surrounding wall.

b) Latrine spot-checks. The main indicators included a well-worn path to the latrine, presence of cleansing materials inside or near the latrine, wetness of the slab or latrine floor, dis-colouration of pan, and the presence of odour and faeces. At least 4 criteria were met in latrines of 35% (53) ISHHs. However, it was observed that many latrines were roofless and HHs reported that they would remain so even in the rainy season. Latrines in approximately 16% (24) ISHHs did not meet any of the above mentioned criteria, the pans were filled with dirt and leaves or there were cobwebs in the latrine super structure. Additionally, at least 14% (21) ISHHs were found to be using their latrines for storage of wood/ grains/ other materials. In some cases, where the pan was observable, it was found to be covered with a wooden/ ply board and the materials were placed in the latrine. On probing, some of the reasons cited for non-use were lack of easy access to water throughout the year, namely the dry season; open defecation considered a traditional behaviour; the convenience of using post-harvest fields for defecation; and inappropriate location of the latrine, for example, at the entrance to the house. Based on an affirmative response to three spot-check indicators considered in this pilot, including presence of cleansing materials inside or near the latrine, wetness of the slab or latrine floor, dis-colouration of the pan, 48.6% (73) ISHHs had latrines that appeared to be used.

c) Reported use by households. Pilot test results of this module of the survey revealed the following: (i) Respondents easily grasped the question on "'usual place of defecation" and appeared to report with equal candour on those members that used the latrine always, sometimes, as well as others that always defecated in the open regardless of access to the household latrine. (ii) Women in the household reported that they were primarily responsible for maintaining and cleaning the latrine and also for providing water for latrine use to family members. (iii) It was observed that if other members of the family were present during the survey process, the primary respondent often asked the relevant individual directly about latrine use. (iv) It was observed that some households had visitors who also had access to the household latrine during this pilot study.

Table 5-2: Pilot test results of the survey-based measures of latrine use – latrine construction and functionality, latrine spot-check and reported latrine use (December 2011-February 2012)

Measure of latrine use	**Results**
Latrine construction and functionality	• Variation in latrine construction quality across sub-contracted NGOs in the seven trial Blocks in Puri district. • The height of the latrine enclosure ranged from full height (joined to the roof) to no enclosure. The WaterAid criterion of enclosure of five feet was not met consistently. • The material of the latrine enclosure included cloth/ plastic/ sack, bamboo/ coconut mat, stone, un-plastered bricks, plastered bricks, plastered brick with tiles. • Latrines did not consistently have a latrine closure/ door over the entrance. • The type of latrine closure/ door varied to include wood, curtain or cloth, plastic sheet, metal sheet. • Latrines did not consistently have a roof. Some were partly covered to provide temporary shelter over the pan. • Provision of a Y-connector for the installation of a second pit in the future only in some latrines. • Three households reported using latrines that did not have a door/ closure or a wall/ enclosure.
Latrine spot-check (- well-worn path to the latrine, -presence of cleansing materials inside or near the latrine, - wetness of the slab or latrine floor, - dis-colouration of pan, - the presence of odour and faeces.)	• At least 4 criteria were met in latrines of 35% (53) ISHHs. • Three criteria, including presence of cleansing materials inside or near the latrine, wetness of the slab or latrine floor, dis-colouration of the pan, were met in 48.6% (73) ISHHs. • Some latrines were roofless and ISHHs reported them as remaining so through the year. • Latrines in approximately 16% (24) ISHHs did not meet any of the five criteria. • The above 16% (24) ISHHs had latrine pans that were filled with dirt and leaves or there were cobwebs in the latrine super structure. • 14% (21) ISHHs were found to be using their latrines for storage of wood/ grains/ other materials. • Reasons cited for non-use of latrines: lack of easy access to water throughout the year, namely the dry season; open defecation considered a traditional behaviour; convenience of using post-harvest fields for defecation; inappropriate location of the latrine, for example, at the entrance to the house.

Reported latrine use	• Easily understood "usual place of defecation". • Unhesitating and prompt response when queried about defecation practices of family members, including open defecation behaviours. • Women in the household primarily responsible for provision of latrine water and latrine maintenance. • Observed that respondent directly consulted other family members present when queried about their latrine use behaviour. • Presence of visitors in some households who had access to the household latrine.

5.4.1.3.4 Conclusions

- Timing of conducting the surveys: Based on the experience and learning from the pilot study, it was decided that the complete latrine construction and functionality, latrine spot check and reported use surveys would be conducted on all households in the first visit of a given data collection round where the PLUM was not to be installed. In households where the PLUM was to be installed, only the latrine construction and functionality and reported use surveys would be conducted, except for queries regarding the 48 hour recall period. The latrine spot-check and the 48 hour latrine use recall components would be conducted on the same households at the end of the observation period during PLUM removal. This would help stream-line logistics, minimise temporal distance between the conduct of the spot-check and the PLUM recorded latrine use data, and ensure that the 48 hour reported latrine use recall overlapped with the PLUM data obtained for the same period to enable a valid comparison between the two measures.

Latrine construction and functionality:

- The variation in latrine construction by the sub-contracted NGOs across the seven study Blocks implied that sampling of villages for the study would need to be done randomly at the Block level to account for observed variations in this regard.

- The variation in latrine super-structures meant that both the presence/ absence of a specific structural feature and the material used to make the feature should be recorded. For example, the survey should record the presence/ absence of a latrine closure or door over entry for privacy and the type of latrine closure/ door, if one existed, which could be made of wood, cloth/curtain, plastic sheet, metal sheet, any other.
- The indicator, height of the latrine closure, was adjusted to field-based observations and the survey options would include “no enclosure/ enclosure less than four feet/ four foot enclosure/ full height of enclosure (i.e., person’s head not visible while squatting)/ others”.
- Based on the TSC specifications of providing a Y-connector in the pipe connecting the pan and pit for the construction of a future second pit, provisions were also made to collect data on the second pit in the survey tool.
- The pilot findings resulted in a modification of the WaterAid definition of a completely constructed and functioning latrine. Since three households reported latrine use in structures with a missing door or an enclosure/ wall, a pared down definition of latrine construction and functionality may be required.

Latrine spot-check:

- The observation that some households with roofless latrines that remain so throughout the year, including in the rainy season, implied that the indicator, “wetness of slab or latrine floor” may not be valid to assess latrine use in the rainy season.
- Even those 16% (24) ISHHs with latrines that did not meet any of the five identified criteria (refer to Table 5-3), were included to review the nature of the PLUM signals in latrines that do not appear to be used. No PLUM signals were obtained in these latrines.

- The finding that 14% ISHHs had latrines that were being used for storage influenced the decision to include the indicator in the spot-check survey: "evidence that the latrine is used for storage". This is a strong indicator with the potential to offer relatively conclusive evidence for or against latrine use.
- The need to separate specific indicators that were clubbed together during the pilot, for example, odour of stool/urine and presence/traces of faeces in pan, would remain in the survey but as independent indicators.
- The inclusion of the indicator: "leaves/dirt/spider webs in the pan" to indicate use or non-use, as the case may be.
- Although only anecdotal, the reasons cited by respondents for non-use of latrines provided preliminary insight into some potential determinants of latrine use within the study population. As a result, the inclusion of a separate question in the survey to record the reason(s) for non-use of latrines was considered.
- The extent of use was challenging to assess based only on spot-checks of latrines. Drawing from this, it may be useful to incorporate an indicator on the presence of human stools in the household compound to validate spot-check as a measure of latrine use. However, it was observed that not all households have clearly defined compounds and that it is particularly challenging to determine which household is responsible for defecation when households are tightly clustered.

Reported latrine use:

- Respondents appeared to be fairly candid about reporting site of defecation, including open defecation, for themselves and their family members. This indicated that potential reporting bias may be less than expected in the study population.
- The primary respondents in the survey were identified as women given their role in providing water and latrine maintenance. Further, a preference order among potential adult female respondents based on traditional family hierarchies needed to be established to standardise data collection procedures. For example, identification

of the adult female could begin with the mother-in-law (female head of the household), followed by the eldest daughter-in-law etc.

- Importance of noting whether the response was reported and self-reported since it was observed that other members of the family are typically present during the process and the primary respondent often asks the relevant individual directly, if he/ she happens to be present.
- Importance of noting, and accordingly recording, the number of visitors or outsiders who may have used the latrine while reporting latrine use over the previous 48 hour recall period. This would potentially ensure greater accuracy in recall by respondents and aid comparison with the PLUM-based measures obtained for the same period.

5.4.1.4 Estimation of a defecation frequency standard for the (rural) study population

5.4.1.4.1 Objective

To estimate the average frequency of defecation events per day per person as reported by a sample drawn from the (rural) study population.

5.4.1.4.2 Methods

During the pilot conducted in December 2011 - February 2012, where 150 ISHHs across 38 villages were included in the study, a question was asked at the outset on the first visit to every household after obtaining consent. Respondents were asked to self-report the number of times they typically defecate, regardless of the location, gender and age. In the case of infants and children under five years of age, the primary care giver was asked to report on their defecation frequency. The objective was to get self-reported data on a sample of at least 1500 individuals. No specific sample size calculations were undertaken to arrive at this number. This data was collected until at least 1500 such responses were obtained. The age and gender of each of the respondents was noted.

5.4.1.4.3 Results

Data was obtained on 1576 individuals. Descriptive statistics on the data set revealed the following: Overall, the maximum number of respondents (n=1128) reported defecating at least twice a day (Table 5-3). This was followed by 331 respondents who reported defecating at least once a day.

Table 5-3: Reported usual frequency of defecation events, regardless of site, gender and age, in a sample of 1576 individuals.

Self-reported frequency of defecation events	**Frequency**	**Percentage (%)**
Usually 1/day	331	21.00
Usually 2/day	1,128	71.57
Usually 3/day	98	6.22
Usually 4/per day	13	0.82
Usually 5/day	3	0.19
Usually 6/ day	1	0.06
Don't know	2	0.13
Total	1,576	100.00

Among 1574 respondents (male = 48.3%) who were able to report on their average frequency of defecation events per day, the mean defecation frequency was found to be 1.88 events/person/day (std.err = 0.014, 99% CI = 1.84, 1.91). The mean defecation frequency for male respondents was found to be 1.97 events/person/day, while for females it was found to be 1.79 events/person/day.

The mean defecation frequency per day by age (Table 5-4) showed that the mean defecation events/person/day ranged from 1.79 events/person/day for the age group 4-12 years to 2.21 events/person/day for the age group 71-79 years.

Table 5-4: Mean defecation frequency/person/day by age groups (N=1574).

Age group	Mean events/person/day	Number of respondents
0-3 yr	1.82	56
4-12 yr	1.79	295
13-55 yr	1.87	1000
56-70 yr	2.03	192
71-79 yr	2.21	14
80+ yr	2.06	17
Total	1.88	1574

5.4.1.4.4 Conclusions

These results indicate that based on self-reported average defecation frequency, the mean defecation frequency per person per day may be considered to be 1.88 events/person/day for this rural study population. It may be reasonable to assume that since this data was gathered in the initial stages of the study and that respondents were not asked about the site of defecation, response bias has been minimised. It may be mentioned that the mean values do not appear to differ greatly either by gender or by age. This mean defecation frequency/ person/ day estimate along with evidence from a previous study (Manas Kumar et al., 2013) may be used as references to characterise likely frequency of latrine use for defecation at the household level where PLUM-based or 48 hour recall self-reported latrine events are obtained.

5.4.2 Phase 2 pilot testing (June 2012 - September 2012): SweetSense (SS) PLUM and finalisation of additional methods to assess latrine use

This phase of pilot testing included the testing of the SS PLUM in two rounds and the finalisation of the survey-based methods to assess latrine use.

5.4.2.1 Testing of the SS PLUM

5.4.2.1.1 Pilot testing: Round 1 (June 2012)

The Portland State University (PSU) team brought 50 units of the SS PLUM to Bhubaneswar, Odisha, in June 2012. We decided that Round 1 would involve testing the units in both laboratory and small-scale controlled field settings.

Laboratory testing: The units were fitted with SIM cards and batteries. The MAC address of each sensor was checked to ensure that the unit was ready to log data and transmit it using the local cellular service. Four units were found to be mal-functioning or broken and were kept aside. The remaining 46 units were placed in various corners of the laboratory and were left on throughout the day and overnight to check for recording and transmission capabilities. We found that two units did not record data, requiring additional hardware checking. Door switches were also arranged for units that would be tested on a small-scale in the field.

Figure 5-14: The first version of the SweetSense PLUM (June 2012) – the internal fitting and the encasing

Small-scale field testing: The next step entailed testing the units and the door switches in two villages that were not part of the Sanitation Trial. Bhoigun and Aruha, which are relatively close to Bhubaneswar, had an adequate number of latrine-owning households as a result of the TSC, and also seemed to have satisfactory cellular service coverage. Five households that consented to participate in the pilot study were selected from each of the villages. It was decided that after installation the units would be left overnight to assess functionality. In addition, door switches would also be installed to offer a secondary data source to validate PLUM-based latrine events by recording the frequency of movement of the latrine door (Figure 5-15). The data transmission time was set for two hours to enable frequent monitoring of the device. We carried a smart phone to enable us to read or register the MAC address of the device on the website post installation. This would help ascertain whether the device was activated and functioning in the latrine.

In Bhoigun, the PLUM units were deployed in five households (with one latrine each) that consented to participate in the pilot. We found that we were unable to register the unique ID of three PLUM units even when less than five feet from the household. On walking around, we identified significant variation in cellular coverage with certain zones that showed no coverage at all. Two PLUM unit IDs did get registered thereby enabling re-setting of the on-board time clock to match local time. We decided to remove the three units that were not being read and leave the two working units until the following day. Door switches were installed in latrines of two households.

Figure 5-15: The door switch installed in latrines during the Phase 2 pilot testing in Bhoigun, rural Odisha, in June 2012.

The process of installing door switches proved to be challenging because (i) the types of latrine doors or closures varied, including metal sheets, curtains and temporary, detached covers to block the entrance as required, (ii) poor quality wood that prevented the unit from being attached firmly in place to the door frame and the door, (iii) wiring for the unit that allowed for potential tampering and disconnection, especially if accessed by children, (iv) poorly fitted closures or doors that lacked alignment and therefore did not close adequately for the door switch to reliably capture all latrine door motion for the given time. Based on this, a decision was taken to prioritise testing of the SS PLUM units and later explore the possibility of deploying the door switches in select households that met the necessary conditions for installation.

In Aruha, we experienced similar issues regarding variability in cellular coverage. Only two units were deployed in latrines of households and left overnight. No door switches were installed.

Given the issues mentioned above, we further tested five units in five households in Saliasahi slum settlement in Bhubaneswar for two days after obtaining written consent from participating households. The site was selected in Bhubaneswar itself as it has good cellular coverage. This was done to also exclude other potential hardware and software issues that could impede device functionality. The data transmission time was set to two hour intervals. One unit was intentionally installed in a latrine with no reported use to examine the nature of signal output in case of non-use. All five units were registered on our smartphone post installation, even at a distance of 30-40 feet from the participating households, thereby demonstrating that the devices were activated as anticipated. We were able to monitor data logging of these five units in real time from our office. The main learnings from this pilot were (i) in case of non-use, a functional SS PLUM does not log any data and only shows the pre-set transmission time (whereas a mal-functioning device is not likely to record either), (ii) cellular coverage is likely to vary in the study villages. A SD card back up is therefore necessary in the device to ensure that data may be logged regardless of quality of the available cellular service. A protocol for deployment of the SS PLUM was developed on the premise that if the cellular coverage is poor, the SD card will record data as a back-up.

Latrine activity simulations: To further refine and inform the algorithm for a likely “latrine defecation event” derived from SS based raw data, latrine activity simulations were done in one consenting household (of the five mentioned above) in Saliasahi slum in Bhubaneswar. A SS PLUM unit was fitted in the latrine. Three family members and two researchers, of which one was responsible for timing and recording the events using a stop-watch, participated in this process. Actual field-based case scenarios that were developed based on observations from previous rounds of testing were executed. For example, mother and child in latrine; one adult individual in latrine; the duration of an actual urination event; the duration of a defecation event; cleaning of latrine; child faeces disposal; among others. The nature and accuracy of signal output from the device was compared with recorded time using a stop-watch. However, due to the limited number of simulations, this data was not finally used to inform the algorithm. It was decided to only validate the SS with signal output from the 2G and structured observations (Section 5.3.2.2).

5.4.2.1.2 Pilot testing: Round 2 (July - August 2012)

SS PLUMs were deployed in 40 latrine-owning ISHHs in six study villages for three days following the protocol developed by the product developer. The two main issues that emerged were:

(i) Varying cellular network, which required us to stand in the latrine to check for coverage using our smartphone. If it was poor, we identified a spot in the village with good coverage, and then switched the unit to SD card mode in that zone as per protocol. The process was time-consuming and inefficient.
(ii) 28 units did not record data. The diagnosis was that the extreme humidity, and rainfall in roofless latrines, was effecting the on-board time clock and preventing its re-setting to local time by communicating with the closest cellular tower. There were also instances of battery leakage and water seepage into the unit that damaged the mother board.

Based on these observations, the following modifications were made. First, with respect to the deployment protocol, all units were re-set in SD card mode in the laboratory one night prior to deployment in the field. Five units that were re-set following this protocol were deployed in three researchers' homes where there was poor cellular coverage for two days to confirm that data was getting recorded as expected on the SD card. Second, with respect to the SS PLUMs, the external casing was changed to a water-proof unit and a de-humidifier was inserted below the mother board.

After pilot testing and re-fitting the PLUMs in the new water-proof casing, the total number of functional units available for deployment in the study was 32.

As mentioned in Section 5.3.2.2, the SS PLUM interpretation algorithm was also validated against the 2G PLUM and structured observations in August 2012.

5.4.2.2 Testing and finalisation of additional methods to assess latrine use

All three survey-based modules, latrine construction and functionality, spot-checks and reported use underwent a final round of testing in 20 households in Bhoigun and Aruha villages after obtaining consent from participating HHs. This was done to finalise the instruments and back-check the local language translations. Only minor language modifications were required in the instruments.

6 Methods to assess latrine use

Chapter 5 described the methods for developing and piloting of approaches for assessing latrine use. In this chapter, we describe the methods under which the final approaches were applied to assess latrine use in the context of a large cluster randomised trial (CRT).

6.1 Study context: The Sanitation Trial

The need for the Sanitation Trial: The latrine use assessment study was a sub-study of a cluster randomised trial to assess the effectiveness of a rural sanitation intervention, within the context of GoI's TSC, to prevent diarrhoea, soil-transmitted helminth infection and child malnutrition. Although sanitation has been recognised as "the greatest medical advance" since 1840 (Ferriman, 2007), evidence of the health effect of household sanitation in low-income countries from large RCTs was lacking (Clasen et al., 2012a). Additionally, evidence from the Sanitation Trial could also contribute to rural sanitation policy and bolster understanding of the health and social benefits of and demand for sanitation among users (Clasen et al., 2012a).

Setting: The cluster randomised sanitation trial was conducted between May, 2010 and December 2013, in 100 villages in rural Puri district, a coastal region in Odisha, India. The study villages were spread across seven Blocks (an administrative sub-district) of Puri district (Figure 6-1). Findings from a baseline survey (Table 6-1), also described elsewhere (Clasen et al., 2012a, Clasen et al., 2014), showed that Odisha has an agrarian economy and more than 50% of the population is classified as living below the poverty line by the Government of India. Odisha ranks among the worst Indian states, with only an estimated 18.7% rural households having access to a latrine (National Sample Survey Office, December 2013). A pre-trial estimate from 2008 indicated that sanitation coverage was 15% in rural areas in Puri district (Household, 2010). Also, Puri district is not covered by any regular de-worming programme (Clasen et al., 2014).

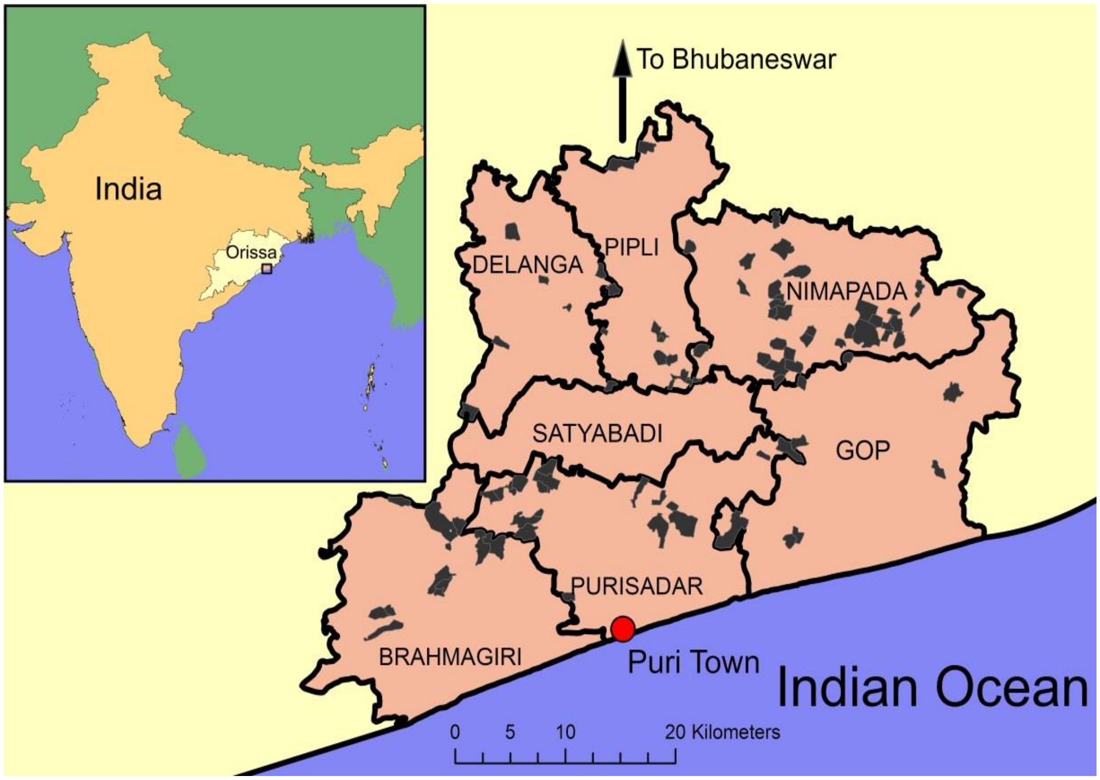

Figure 6-1: A map depicting seven Blocks in rural Puri district, Odisha, India, from which 100 study villages were selected for inclusion in the Sanitation Trial. 50 villages each were randomly allocated to the intervention and control arms stratified by Block. (Prepared by Schmidt W., March 2012, for the Sanitation Trial)

Table 6.1: Characteristics of the study population at baseline survey (n=1992) (Clasen et al., 2012a)

Parameter	**Intervention**	**Control**
Average persons /HH (SD)	6.4 (2.8)	6.3 (2.8)
Education level-HH head, %		
None	27	31
Primary school not completed	22	19
Primary school completed	39	34
Some secondary school	12	17
Education level-caregiver, %		
None	17	17
Primary school not completed	14	12
Primary school completed	50	50
Some secondary school	18	21
Has BPL card	42	45
House structure		
Cement wall and roof (‘*pucca*’)	42	37
Cement wall (semi-‘*pucca’*)	21	20
No cement wall (‘*kuchha*’)	37	43
Electricity, %	79	73
Owns agricultural land, %	76	74
Owns poultry/livestock, %	59	59
Water source, %		
Piped water	3	4
Deep tube well	38	39
Shallow tube well	41	44
Open well	9	2
River/lake/pond/canal	5	7
Other	4	4
Location of water source, %		
In own dwelling	18	15
In own compound	13	12
Outside compound	70	73
Access to a latrine, %	10	11

HH: household; BPL: Below Poverty Line, certified by a government-issued card.

Eligibility criteria and enrolment: The 100 study villages were selected from a list of 385 villages that had not yet been covered by the TSC. A baseline survey was conducted between September and October 2010 to gather data on household demographic characteristics, SES, water, sanitation and hygiene conditions and diarrhoea prevalence (Clasen et al., 2012a). Village eligibility was based on sanitation coverage of less than 10%; improved water supply; and no other planned WASH intervention for the following 30 months. Households were eligible if they had a child less than 4 years (verified by an immunisation card) or a pregnant household member. Households with babies born during the surveillance phase were also enrolled in the study (Clasen et al., 2014, Clasen et al., 2012a).

Study design: The study was reviewed and approved by the ethics committees of the LSHTM (London, United Kingdom), Xavier Institute of Management (XIMB) and the Kalinga Institute of Medical Sciences, both in Bhubaneswar, India. LSHTM and XIMB led the study but did not directly influence the delivery or the type of intervention. The study was a cluster randomised trial with villages as the unit of randomisation (Clasen et al., 2012a). The study followed a parallel trial design where 50 villages each were randomly allocated to the intervention and control arms stratified by Block to ensure an equal number of clusters in each arm (Clasen et al., 2012a). Randomisation also ensured a fair balance of socio-economic and water and sanitation-related characteristics between the two arms. The intervention, which was aligned with GoI's TSC, comprised latrine promotion, construction and community mobilisation activities with a post-hoc subsidy for BPL households. The control arm would receive the intervention after trial completion (Clasen et al., 2012a).

Intervention: WaterAid India (part of WaterAid, an international NGO) and the United Artists Association (an Odisha-based water and sanitation NGO) were responsible for coordinating the implementation and roll-out of the TSC programme in Puri (Boisson et al., 2014). Six local NGO partners were sub-contracted to deliver the programme along with the local self-government (the *'Gram Panchayat').* In the intervention, the basic latrine option comprised a pour-flush (water seal) latrine with a single pit and Y-joint for a future second pit (partly depicted in Figure 6-2). BPL households received a subsidy of USD 44 (INR 2,200), the prevailing subsidy at the time of construction in January 2011, from the government on construction of the toilet. This covered costs for three pit liner rings and cover plate, two bags of cement, one Y-connector, one connector pipe, one ceramic pan set and one door. Households were required to contribute sand, bricks or stones for the superstructure, and labour to dig the pit. It did not include the cost of the super-structure. APL households did not receive any government subsidy on the assumption that they would be motivated to construct latrines as a result of exposure to the IEC campaign. However, WaterAid India provided equivalent funding for certain APL households that were headed by a widow or had a disabled member. Under the TSC, construction materials were made available through local construction centres and rural sanitary marts that were established to strengthen the supply chain (Boisson et al., 2014).

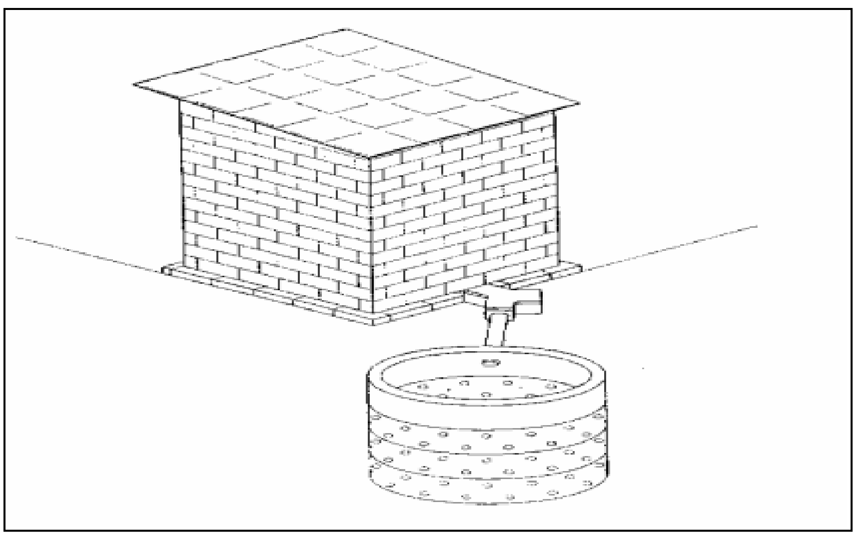

Figure 6-2: WaterAid India's criteria for a completely constructed and functional latrine - brick structure (3. 6 ft. width, 4 ft. length and 5 ft. height); door; single pit and chamber connection for second pit, ring pit with cover plate (WaterAid India, 2010)

Implementation was initiated by the collaborating partners in January 2011 and continued until January 2012 (Clasen et al., 2014). A process evaluation of the intervention process revealed that the percentage of households with a latrine (completed or under construction) increased from 9% (baseline) to 63% (follow-up) (Clasen et al., 2014). The study findings also revealed that the levels of coverage achieved and awareness of mobilisation activities in the intervention villages was lower than originally planned (Boisson et al., 2014).

Study outcomes: Health outcome measures included (i) reported seven day diarrhoea prevalence in children under 5 years. The WHO definition of diarrhoea, which is three or more loose stools in 24 hours, was used in the study. (ii) The combined prevalence of three common soil-transmitted helminth worms, hookworm, roundworm and whipworm, was also assessed in study participants aged 5-40 years from all enrolled households before completion of the intervention. The data was compared with a baseline measurement that was taken in June-July 2011. (iii) Anthropometric measures that used weight-for-age Z scores for children <5 years and height-for-age Z scores for children <2 years. The trial also assessed intermediate environmental outcomes (iv) faecal contamination of drinking water stored in households of the study participants; (v) exposure to faecal pathogens in the environment; (vi) number of insect vectors (flies, mosquitoes) and the extent to which flies that are present carry pathogens. The study included process documentation of the intervention; cost and cost-effectiveness analyses; spatial analyses (Clasen et al., 2012a). Furthermore, the study included an assessment of latrine use; an evaluation of methods to assess use; and an evaluation of factors associated with latrine use (Section 6.2).

Partners and funders: The study partners included LSHTM; XIMB; Kalinga Institute of Medical Sciences and the Loyola Hospital, Bhubaneswar; WaterAid India; United Artists Association and their collaborating partners. The study was funded by the Bill & Melinda Gates Foundation, the International Initiative for Impact Evaluation (3ie), and the Department for International Development funded SHARE Research Consortium at the LSHTM.

6.2 Assessing latrine use in the context of the Sanitation Trial

This research pertains to a sub-study conducted in the context of the Sanitation Trial. A 12 month field study was undertaken to evaluate the methods for assessing latrine use and to assess latrine use in the study population. Although latrine use data was collected using four methods, which included a smart device, the PLUM, reported latrine use, latrine spot-checks and latrine construction and functionality indicators, this thesis will primarily focus on two methods, the PLUM and reported latrine use. Further details are provided from Section 6.2 onwards. In addition, compliance with the intervention was also assessed using a survey-based measure at the mid-point of follow-up using a cross-sectional design. This was led by another research colleague but the researcher helped in developing the survey tools for this component. The survey recorded latrine presence and functionality, reported latrine use, observable indicators of latrine use and global position system (GPS) location of latrines and households.

6.2.1 Study design

An observational study was designed in the context of a cluster randomised trial to evaluate methods for assessing latrine use, assess latrine use among latrine-owning households, and to explore patterns and determinants of latrine use. The study was designed around latrine use as the primary outcome. As described in Sections 5.2 and 5.3, this study used a mixed methods approach to assess latrine use. PLUM-based latrine use, which was measured in terms of a point estimate of the mean daily PLUM-based latrine events at a household-level, was considered a relatively objective indicator of use. It provided potentially comparable data to the four categories of survey-based reported latrine use measures at a household level (that is, “usual” or average daily latrine use; latrine use “yesterday” or the last day of the observation period; latrine use the “day before yesterday” or the second-last day of the observation period; and latrine use in the last 48 hours of observation); and a likely means for assessing the extent to which the categories of reported latrine use may be subject to bias.

In order to assess whether and to what extent individuals in the study households use the latrines, the least biased (and most precise) reported latrine use measure of the corresponding PLUM-based estimate was selected. At an individual level, this estimate was compared against an assumed rural household defecation frequency standard. Based on the results of a previously published study of defecation frequency in this region (Manas Kumar et al., 2013) and an analysis of pilot data collected prior to initiating field work (Section 5.4.1.4), a conservative assumption was made that in this rural context, each person per household is likely to defecate at least once per day and at least two or more total events over the prior 48 hours. Individuals that did not use the latrine on both days were considered "never" or non-users. To qualify as a "sometimes" user, the individual must have used the latrine at least once on either of the two days. To be included in the "always/usually" use category, individuals were expected to have used the latrine at least once on both days. Therefore, we developed a three-way classification of individual latrine use, corresponding to "never", "sometimes", "always/usually". This required a population-based sample from study households with children under five from the selected villages.

The data collection rounds coincided with the three seasons. In order to examine the consistency of latrine use over time/across seasons, we constructed a longitudinal measure of latrine use from participants' responses to the 48 hour recall measure at each study round. The longitudinal use measure was defined by the following criteria: "never" use included those with 0 events on both days per round resulting in 0 events over all 6 days; "always/usually" use was defined as ≥ 1 event per day per round resulting in ≥ 6 events over all 6 days; and "sometimes" use was defined as <1 event per day per round in any of the 3 rounds with total events > 0 but <6 across the 6 days of queried use.

We also had secondary measures of latrine use at a household level through latrine spot-checks. This offered a relatively quick basis for assessing household level latrine use and enabled a sensitivity and specificity analysis to predict the results from reported use and PLUM-based measures.

The study was conducted in a computer-generated random sample of 25 of the 50 intervention villages, stratified at the Block-level. The households enrolled in the study were selected from among the intervention households with children under five years whose health outcomes were being assessed in the Sanitation Trial; these are referred to herein as the “intervention surveillance households” (ISHHs).

The study comprised three rounds of data collection over 12 months. As we expected that latrine use may vary seasonally, this ensured that all seasons were covered, including the dry hot, rainy and dry cold seasons.

6.3 Sample size

6.3.1 Sampling strategy

As mentioned in Section 6.2, the primary outcome of this research study was latrine use. The sample size calculations were based on the main research objectives and study outcomes:

a. To evaluate methods for assessing latrine use: This was measured in terms of categories of reported latrine use events and comparable PLUM-based events, the main outcome variables. This required a population-based sample from households with children under five from the selected villages. To enable a comparison of reported use and the PLUM with spot-check/indicators of use also required the same population-based sample as mentioned above.

b. To assess individual latrine use based on reported use: In a given season, this was measured in terms of a point estimate of mean daily reported latrine events over the previous 48 hours (the outcome measure) at an individual level. As mentioned above, the outcome measure was characterised into “always/usually”, “sometimes” and “never” users. Consistency of use across three seasons was measured over six days and was similarly characterised into “always/usually”, “sometimes” and “never” users. This required a population-based sample from households with children under five from the selected villages.

c. To explore seasonal variations in latrine use: This required repeat measures from the same households at different times (corresponding to the seasons). The mean daily reported latrine events over the prior 48 hours were the outcome variable.

d. To explore determinants of use: These were both individual and household-level predictors with reported latrine use events in the previous 48 hours as the outcome variable. It was considered sufficient to sample from intervention surveillance households.

6.3.2 Sample size estimation

The initial sample size estimation was driven mainly by the PLUM-based data of a sample of 30 ISHHs from the pilot study (Section 5.4.1.2.2.3, Table 5-1). Since the PLUM device failure was not linked to any specific latrine or household characteristic, these 30 households were considered representative. The details included:

(1) the mean number of PLUM-based latrine events per person per household per day (which is: total number of PLUM-based latrine events/ total number of observation days/ number of members in the given household);

(2) the standard deviation of the mean PLUM-based latrine events per person per household per day;

(3) the intra-class correlation coefficient for the repeated measurements (days) within a household.

It was assumed that in order to address the research questions, the data analysis would require a comparison between two groups or sets of households (e.g., households in the highest wealth quintile with households in the lowest wealth quintile etc.). Additionally, some comparisons would be done between the same households at different times (e.g., a set of household measures in the dry hot season and the rainy season etc.). The pilot data indicated that within household variance was lower than between household variance, thus implying that over the given observation period, latrine use counts within a household tend to be more similar than those between households. From the pilot study, we calculated an intra-class correlation coefficient (ICC) of 0.38, which was used to calculate the design effect, *Deff.* The sample size calculation was driven mainly by the within (intra) household correlation of PLUM-based latrine events. The pilot data also suggested that the within village ICC was 0 and was therefore not considered in the calculation. The pilot study did not offer data on the between measurement (same households at different times) standard deviation required to make an informed sample size calculation. However, it was assumed that the required sample size for these comparisons would be *lower* than for two independent samples because the between-household variation in PLUM-based latrine events, which was considerable, was removed. Therefore, the calculations are likely to be conservative.

Based on the PLUM-based pilot study data from a sample of 30 households, the following assumptions were made:

(a) mean PLUM-based latrine events per person per household per day in group 1 households (mean1) = 0.30;

(b) mean PLUM-based latrine events per person per household per day in group 2 households (mean2) = 0.35 (assuming that even small changes between two groups are to be detected);

(c) alpha = 0.05;

(d) power = 0.8;

(e) Sd1 = 0.21, Sd2 = 0.21;

(f) n2/ n1 = 1.00.

Using the formula for comparison of two means to give an estimate of the sample size per group (Kirkwood and Sterne, 2003):

$$(u + v)^2 (sd1^2 + sd2^2) / (mean1 - mean2)^2$$

where u = one-sided percentage point of the normal distribution corresponding to 100% - the power and v = percentage point of the normal distribution corresponding to the (two-sided) significance level. Therefore, estimated required sample sizes per group in order to detect the difference would be: n2 = 277, n1 = 277.

The amount of clustering can be measured by intra-class correlation coefficient (ICC), which is defined as the ratio of the between cluster variance to total variance (a combination of between and within cluster variance) (Kirkwood and Sterne, 2003).

$$ICC = {\sigma_B}^2/({\sigma_B}^2 + {\sigma_W}^2)$$

where σ_B = between-cluster standard deviation

σ_W = within-cluster standard deviation

The ICC for repeated measures within a household (in a given round) may be calculated using STATA's *loneway* command. For the pilot study, an ICC of 0.38 was calculated. The ICC was used to calculate the design effect,*Deff,* the factor by which the sample size of a study needs to be inflated to account for clustering.

$$Deff = 1 + (m-1) \times ICC$$

where *m* is the average number of measurement days per household .

Table 6-2: Sample size calculation parameters using intra-class correlation

Parameters	Variables	Estimates (sampsi 0.30 0.35, sd 0.21, p 0.8)	Estimates (sampsi 0.30 0.40, sd 0.21, p 0.8)
Mean person count (group 1)	mean1	0.3	0.3
Mean person count (group 2)	mean2	0.35	0.4
Significance level	α	0.05	0.05
80% power	p	0.8	0.8
Standard deviation 1	sd 1	0.21	0.21
Sample size per group	n	277	70
Intra-class correlation	ICC	0.38	0.38

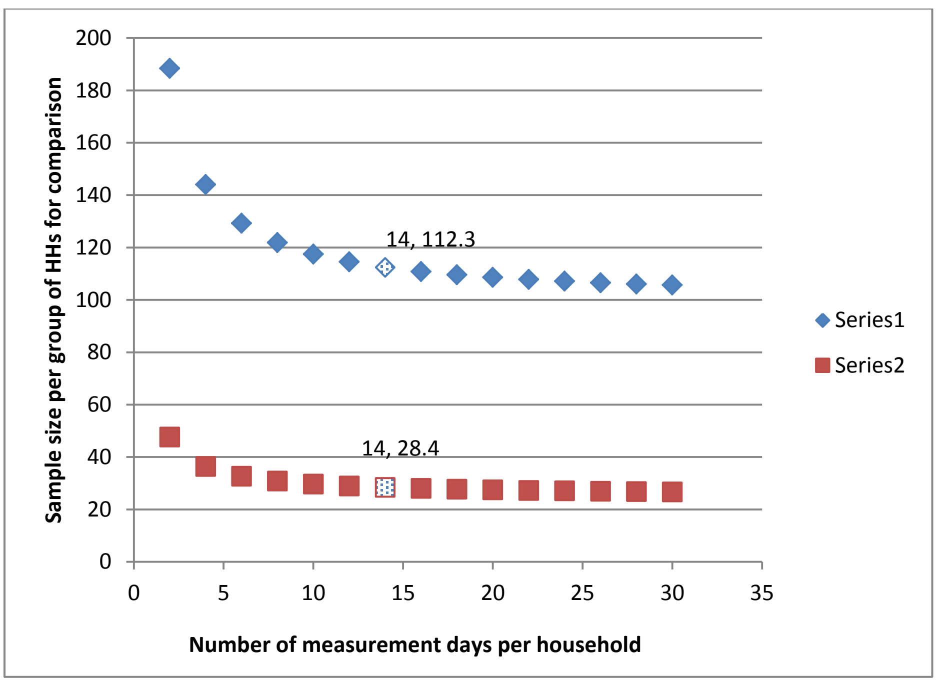

Figure 6-3: Number of measurement days per household versus sample size per group of households for comparison. Series1 refers to sample size estimation per group of households to be compared for a difference of 0.05 mean PLUM-based latrine events to be detected (sampsi 0.30 0.35, sd 0.21, p 0.8). Series 2 refers tosample size estimation per group of households to be compared for a difference of 0.1 mean PLUM-based latrine events to be detected (sampsi 0.30 0.40, sd 0.21, p 0.8).

The graph (Figure 6-3) indicates that there is little additional benefit in sampling more than 14 days in a household per round. The number of required households will not decrease much if more than 14 days are recorded. Thus, 112 households per comparison group, each measured for 14 days, will allow a difference of 0.05 (e.g. 0.30 vs. 0.35) mean PLUM-based latrine events to be detected between two sets or groups of households to be compared. Just 28 households will be sufficient to detect a difference of 0.1 mean PLUM-based latrine events. Based on this analysis, a decision was taken to permit a difference of at least 0.05 mean counts between the two groups being compared.

However, logistical constraints, including the availability of only 32 SweetSense PLUM devices, ultimately determined the sampling plan of the study. This resulted in some variations between the proposed and actual plans. The details are mentioned below:

1. Of a total of 50 intervention villages, 25 villages were selected using a computer generated random sequence. Randomisation was stratified at the Block-level to account for observable differences in quality of latrine construction and the six different NGOs implementing the intervention as part of the TSC.

2. With reference to the PLUM-based measurement, three randomly selected (using a computer- generated sequence) and consenting intervention surveillance households with latrines per village were identified for repeat measures in each round. This enabled repeat measures from a total of 75 households per round.

3. Again, with regard to the PLUM-based measurements, all the remaining eligible households per village were randomly assigned (using a computer-generated sequence) into 1 of the 3 rounds to ensure that each round had an approximately equal number of households at a village-level. The main criteria for deployment of the PLUM device were the presence of a latrine and if latrine construction was complete. As described in Section 5.2.3, a clear definition was established for a completely constructed and “functional latrine”.

4. The assessments of reported use, spot-checks, and latrine construction and functionality were done on all eligible households in each of the 25 selected villages per round. This enabled survey-based data on latrine use and structural monitoring of the latrines at three time points per household.

6.4 Participant eligibility, enrolment and randomisation

All 50 villages comprising the intervention arm of the Sanitation Trial were eligible for inclusion in the study. However, enrolled villages had to meet the criterion of having at least one intervention surveillance household with a constructed and "functional" latrine as a result of the intervention. Households, from among the intervention villages, which had children under five years or pregnant women and were being monitored for health outcomes, had constructed latrines and were exposed to the IEC campaign as a result of the TSC intervention, were eligible to participate in the study. All members in the enrolled surveillance households were included in the study (subsequently only those >3 years were included in the analysis).

In the pilot study conducted in December 2011-February 2012, we verified that only 46 villages met the eligibility criterion mentioned above. Of these 46 villages, 25 were selected after computer-based randomisation at the Block-level. Further, at a household level, the PLUM device was only deployed in those with completely constructed and minimally functional latrines (following the definition mentioned in Section 5.2.3). The construction status of the latrine was based on feedback from household members and visual inspection by us.

The following consent process was undertaken prior to enrolling households:

- Meeting with and informing at least one member of the Village Water and Sanitation Committee (VWSC) to explain the purpose of the study and get buy-in for the deployment of the PLUM device in some latrine-owning households in the village.

- Obtaining consent from eligible households regarding their participation in the study and for the installation of the PLUM device in their latrines for the observation period.

As previously mentioned, two-levels of randomisation were performed, at the village level and at a household level, using a computer-based random number generator. First, of the 46 eligible villages that were spread across six Blocks, 25 were randomly selected at the Block-level. This ensured that the sample comprised latrines constructed by all NGOs operating within the study villages. Second, of the total number of eligible households within each of the 25 villages, three were randomly selected from each village comprising households in which repeat PLUM-based latrine use measures would be taken in all three seasons or rounds. In the event that a given household did not consent to PLUM deployment in all three seasons, the next randomly selected eligible household within the village was approached and included. All the remaining eligible households in a given village were then randomly assigned to one of three rounds corresponding to the dry cold season, dry hot season and rainy season and PLUMs were deployed following this schedule. The survey-based latrine use measures were conducted on all eligible households in all 25 villages in each of the three study rounds.

6.5 Field methods

The tools used in the study were finalised after conducting formative research and pilot tests (Chapter 5). The survey tools were printed in both English and the local language, Oriya (Appendix 1). This section details the procedure followed in each surveillance round in each household. However, detailed descriptions of the methods have already been included elsewhere (Section 5.2 and Section 5.3.1.3) and will not be repeated in this section.

(a) Stage 1: Enrolment, surveys and PLUM deployment

First, prior to enrolment, the household was asked whether they have *access* to a latrine. If they responded in the affirmative they were asked whether their household has a latrine or not. If they again responded in the affirmative, the household was enrolled in the study. A request was made to see the latrine and they were asked if they *ever use* it. The <u>construction status and functionality of the latrine(s)</u> (Section 5.2.3) was assessed. The assumption underlying this component was that a completely constructed and/or minimally functional latrine is more likely to be used by members of a household when compared to a latrine that is incomplete and/or dysfunctional. Field workers relied on observation and information provided by the family member (respondent), as necessary.

Based on key indicators in this module, a definition for incomplete latrine construction was developed. The criteria included: pan condition – broken; pits per latrine – none; pit covering open or part open; and pan-pit not connected. An incomplete latrine construction status implied that while a spot-check survey may be conducted; a PLUM device would not be installed in the latrine in the ongoing surveillance round. The status would be re-assessed in the following round of surveillance to determine PLUM deployment.

Second, if a given household latrine met the criteria for complete latrine construction (as defined above) in a given surveillance round, it was considered eligible for installation of a <u>PLUM device</u> in its latrine(s). After installing the unit in an appropriate position in the latrine (Section 5.4.1.1), members of the household were briefed on the device. They were advised to avoid tampering with it and wetting it, as far as possible, for a period of two weeks until the researchers returned to retrieve it. The device was checked to ensure that it was functioning prior to installation. Data from this device was supposed to provide an extended perspective of latrine use in the household relative to the other measures.

Third, in households where the PLUM was not installed, a spot-check survey was conducted to determine latrine use at a given point in time. It emphasised indicators (Section 5.2.2) that were adapted from latrine survey tools used previously in other research (Table 3-2) and also based on field observations. In addition, the presence of human stools in the compound was also recorded as a means of validating latrine use as determined by the spot check.

Fourth, a brief survey on reported latrine use was conducted. The respondent profile was typically an adult female, with a preference for the female head or eldest daughter-in-law of the household. In instances where relevant family members were present and self-reported, the same was noted to further distinguish between reported and self-reported use and potentially minimise bias. The questions have been described in detail in Section 5.2.1.

In households where the PLUM was not installed but the other latrine use assessments were completed, respondents were also asked to report on latrine events of household members from “yesterday” and the “day-before yesterday” to minimise inaccurate reporting from longer recall periods (Hebert et al., 1997). In households where the PLUM was installed, data on these two components of reported use was only gathered at the time of retrieval of the devices. This was done to potentially compare events recorded by the device and those reported by the household over given 24 hour and 48 hour periods.

Fifth, data collection on potential determinants of latrine use was also done to explore associations between latrine use and specific predictor variables. The determinants of latrine use explored in this study were selected on the basis of previous research and on information gathered during the pilot studies. They included socio-economic status (SES), education level, family size, gender and age (O'Loughlin et al., 2006, Jenkins and Cairncross, 2010), distance of latrine from house, proximity to water source and functionality and quality of the latrine (door, roof, walls, pan condition, presence of pit, pan-pit connection and pit covering) (ICRA, April 2011). The distances between the latrine and house and latrine and water source were recorded using GPS readings. Data on other potential determinants, such as family size, SES, education, gender, age and latrine characteristics were gathered using the study survey, which included a SES questionnaire developed by AC Nielsen for the Sanitation Trial baseline assessment.

(b) Stage 2: Completion of latrine use surveillance

At the end of the observation period, the following steps were undertaken:

First, in households where the PLUM had been installed, the last two sections of the reported use survey gathering data on latrine events of household members for "yesterday" and the "day-before yesterday" were completed.

Second, a latrine spot-check was conducted by us in all households where the PLUM was deployed.

Lastly, the PLUM device was retrieved from the latrine. The household was thanked for participating in the ongoing surveillance round of the study and was asked whether they would be agreeable to installing the device in their latrines in subsequent rounds as well. This provided us an estimate of the number of households amenable to repeat PLUM installations in their latrines, based on which we determined whether additional households in the village would need to be approached to secure repeat measurements. In the event of device failure, which did not appear to be linked to any household or latrine characteristic, we decided to re-install a replacement unit for an additional 16 days in the latrine to increase good data rates to the extent feasible, both from a time and logistical perspective. In such circumstances, some survey-based measures were also repeated to ensure temporal contiguity. However, this prolonged the data collection process.

6.6 Outcome assessment

Each household was followed up thrice in the 12 month study period, with one visit in each round for households where the PLUM was not installed and two visits per round for those where the device was installed. These visits included:

- PLUM deployment, reported latrine use survey, latrine spot-check, latrine construction and functionality survey to evaluate methods for assessing latrine use, to assess latrine use both at individual and household levels and to monitor structural aspects of the latrine (objectives 2,3, 4 and 5).
- Socio-economic status survey and recording GPS coordinates of latrines, latrine water source and houses (objective 5).

Household visits were unannounced to capture typical latrine use practices. Table 6-3 summarises the outcome measures that were considered for each objective in the research study.

Table 6-3: Outcome measures for each objective in the study

Objective	**Outcome**	**Measure**
Evaluate methods to assess latrine use: PLUM and reported use measures.	• PLUM-based latrine events and corresponding reported latrine events (excluding individuals age 3 and below).	• "Usual" or average daily reported latrine events and average PLUM-based latrine events over the observation period. • Latrine events for "yesterday". • Latrine events for the "day-before yesterday". • Latrine events over 48 hours measured concurrently.
Assess individual latrine use in TSC latrine-owning households (at a given time).	• Reported latrine use over the prior 48 hours in a given season (individuals >3 years). • Individual characterisation based on level of use.	• Individual reported latrine use events – 48 hour recall. • "Always" latrine using individual: at least 1 latrine event/day on both days. "Sometimes" latrine using individual: at least 1 latrine event on either of the days. "Never" using individual: 0 latrine events/day on both days.
Assess consistency of individual latrine use in TSC latrine-owning households (across three seasons).	• Reported latrine use over the prior 48 hours in all seasons (longitudinal construct of use – individuals >3 years). • Individual characterisation based on level of use across all 3 seasons.	• Individual reported latrine use events (using the 48 hour recall measure) over 6 days. • "Never" use: Individuals with 0 events on both days per round resulting in 0 events over all 6 days. "Always/usually" use: Individuals with ≥1 event/day/ round resulting in ≥6 events over all 6 days. "Sometimes" user: Individuals with <1 event/day/round in any of the 3 rounds with total events >0 but <6 across the 6 days of queried use.
Explore seasonal variation in latrine use.	• % individuals who are "always/usually", "sometimes", "never" users in each season.	• Reported latrine events – 48 hour recall – in the 3 seasons (dry cold, dry hot and rainy season).

Explore potential determinants of: - latrine use in a given season, - consistent latrine use.	• Reported latrine use over the prior 48 hours– in a given season. • Reported consistency of latrine use over the prior 48 hours in all seasons.	• Predictor variables: SES (asset index); education level of household head and primary care giver (completed or not completed primary school);scheduled caste/ tribe (belonging to dis-advantaged groups); family size (number of members living in a household at a given time); gender (male or female); age (number of years since birth); distance of latrine from house (GPS coordinates converted into metres); proximity of latrine to water source (GPS coordinates converted into metres); functionality and the construction quality of the latrine (door, wall, roof, minimally functional indicators – pan, pit, pan-pit connection, pit covering).

6.6.1 Evaluating methods to assess latrine use

PLUM-based latrine events and reported latrine events were the main outcomes evaluated for this objective.

- PLUM-based measures of use: PLUM units were installed in households over a 16 day period at least once in the course of the 12 month study. Days 1 and 16 that corresponded to installation and removal dates were dropped to reduce errors. If a household owned more than one latrine, PLUM devices were installed in each of those latrines.
- Reported use: Data obtained through three main survey questions enabled a valid comparison with PLUM-recorded data for a given household: "usual" or average daily latrine use; latrine use "yesterday" (or the last day of the observation period); and latrine use the "day before yesterday" (or the second-last day of the

observation period). The fourth comparative category, which was latrine use in the last 48 hours of observation, was a derived measure that was a summation of latrine use "yesterday" and the "day before yesterday". These categories were selected to enable a comparative assessment of the two measures in the context of an extended perspective of use ("usual" latrine use behaviour) and a more time-bound perspective of use (latrine use behaviour for "yesterday", the "day before yesterday" and the last 48 hours).

6.6.2 Assessing individual latrine use in TSC latrine-owning households in a given season and across seasons

Latrine use was the primary outcome of this study. Data on reported use was gathered at three time points for each household, corresponding to each of the three study rounds or seasons. Overall, reported use was assessed using four different parameters: a) "ever use" the latrine(s) since time of construction by any household members; b) reported latrine use when asked about "usual place of defecation" for each member of the household; c) reported latrine use when asked how many times a day each household member usually uses it; d) reported latrine use by all members of the household based on prior 48 hour recall, where each day was further dis-aggregated into four segments of the day. Data obtained through c) was based on recall over an extended period to represent typical use behaviour, whereas d) was potentially directly comparable to PLUM-based measures obtained for a given household for the same period. In this component, the respondent was also specifically asked to provide details of any visitors/ non-household members who may have used the latrine in the specified two-day period. This was done in an effort to increase accuracy of reported latrine use.

As presented in Table 6-3, the final latrine use measure that was selected was individual reported use over the prior 48 hours. It enabled a characterisation of individual latrine use (in a given season) into the categories: always/usually, sometimes and never. This was based on an assumption regarding the likely defecation events/ person/ day for the study population. The longitudinal construct of individual latrine use, which assessed consistency of use across all seasons, was based on the prior 48 hour measure in each season. A similar three way categorisation of latrine users was developed that considered frequency of reported defecation events per person per day over a six day period.

6.6.3 Seasonal variations in latrine use

Households were followed up at least once in every season or round, including the dry cold season (October-January), the dry hot season (April-June) and the rainy season (July-September) to obtain repeat measures of reported latrine use over the prior 48 hours. This enabled individual latrine use monitoring in all three seasons.

6.6.4 Determinants of latrine use

The data collection process for this was folded into the monitoring schedule for other outcomes mentioned above. Data on socio-economic status, occupation and education level was only gathered between October 2012 and January 2013. Data on family size, gender and age of users and functionality and quality of the latrine (roof, walls, depth of the pits, pan condition and location) was gathered in each round for each enrolled household. This also accounted for potential variations in the variables over time.

6.7 Data management and analysis

Data were double entered into EpiData 3.1 and analysed using STATA 14. R was used to analyse specific components. The analysis plan was finalised before the data were examined. Individuals aged 3 years and below were excluded from the latrine use analysis (Majorin et al., Submitted, WSP, March 2015).

The evaluation of the two primary measures of latrine use, PLUM-based latrine use and reported latrine use, was made using both the usual latrine use item and the items regarding use in the 48 hour period. The comparison of average reported daily use from “yesterday” and the “day-before yesterday” with the average daily PLUM-based count across the total monitoring period was to determine whether the more targeted recall items had better agreement with overall usage patterns than did the more general "usual use" item. Bland-Altman (BA) plots were constructed to assess agreement between reported latrine use and PLUM-derived count for each of the comparison categories – “usual” or average daily reported use and average daily PLUM-recorded use for a given household; reported latrine use for “yesterday” and PLUM-based events for the same day in the same household; reported latrine use for the “day-before yesterday” and PLUM-based events for the same day in the same household; reported latrine use – 48 hour recall and average daily PLUM-recorded use for the given household for the 14 day (or 12 day) observation period. As the simple Bland-Altman method assumes that both the mean and standard deviation of the differences between methods are constant across the range of measurement, we employed the approach suggested by Bland and Altman to assess these assumptions and adjust the plot for possible violations (Bland and Altman, 1999). The mean difference between methods and 95% limits of agreement were plotted against the average of the methods per conventional BA plot format. Next, to model the direct relationship between the two methods, symmetric prediction equations with corresponding 95% prediction intervals were derived from the results of the BA analysis (Carstensen, 2010). We calculated the concordance correlation coefficient (CCC) with bootstrap 95% confidence intervals (bias corrected accelerated based on 2000 bootstrap replicates) for each pair of measures. To assess for significant differences in the concordance of reported use with PLUM events across the comparison categories, we generated bootstrap 95% CI (2000 replicates) of the difference between CCCs using the approach by Crawford and others (Crawford et al., 2007).

In order to assess individual latrine use in the study population, we characterised individual latrine use based on the prior 48 hour recall measure for any given season. Consistency of use was characterised by the number of reported events across all three seasons or six days of data. SES was measured using an asset index. It was constructed by combining data on household possessions including watch/clock, pressure cooker, telephone, refrigerator, chair, mattress, cot, table, electric fan, sewing machine, water pump, scooter, animal drawn cart, thresher and tractor. Tetrachoric correlation coefficients were calculated for the binary variables. PCA was then applied to the resulting correlation matrix (Howe et al., 2012, Vyas and Kumaranayake, 2006). The first component, explaining 57.7% variance of the items was used in the analysis. Study households were divided into five wealth quintiles based on their asset index, where quintiles 1 and 5 corresponded to the lowest and highest levels respectively.

We examined the association between individual and household-level variables and latrine use using multinomial logistic regression. The regression analysis was done in two stages. First, we regressed the categorical measure of latrine use in the prior 48 hours on all hypothesised determinants of use. Because data collection rounds were timed to correspond with the seasons, this model contained a categorical indicator of the season in which the measurement occurred. Next, we assessed the determinants of consistent use over the 12 month study period by regressing the latrine use measure derived from reported use across all three rounds on the same group of covariates. Models were fit with never use specified as the reference category in order to examine covariate effects on sometimes versus never use and always versus never use. Additional contrasts between outcome categories (e.g. always use versus sometimes use) were derived from fitted models using the *listcoef* command available in the SPost13 package (Long and Freese, 2014). The coefficients from all models were exponentiated to yield multinomial odds ratios, which are interpreted as the effect of a unit increase in the covariate on the odds of being in the specified outcome category rather than the reference category. In addition, we used marginal standardisation to calculate the population-averaged predicted probabilities of use at specified covariate values (Muller and MacLehose, 2014). We adjusted the standard errors and 95% confidence intervals of the coefficient estimates using robust standard errors to account for the clustered structure of the data. Consistent with current recommendations, we adjusted for the highest level (villages) of clustering (Bottomley et al., 2016). In order to assess for potential bias due to a small number of higher-level clusters, we conducted sensitivity analyses adjusting for the next level of clustering, household-level with more than 300 clusters, and obtained comparable results.

6.8 Ethics

The latrine use assessment research was a sub-study of the Sanitation Trial and was granted ethics approval by the Ethics Committee of the London School of Hygiene and Tropical Medicine (Approval #5561, as amended) and by the Institutional Ethics Committee of the Xavier Institute of Management, Bhubaneswar (Approval 310510, as amended). This trial was registered with ClinicalTrials.gov (Registration No. NCT01214785). Participants in the research were explained the details of the study prior to seeking informed, written consent. In addition, VWSC members were also consulted prior to initiation of the study. Measures were taken to ensure confidentiality for all participants.

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SECTION A – Student Details

Student	Antara Sinha
Principal Supervisor	Thomas F. Clasen
Thesis Title	Assessing latrine use in low income countries: a field study in rural India

If the Research Paper has previously been published please complete Section B, if not please move toSection C

SECTION B – Paper already published

Where was the work published?	American Journal of Tropical Medicine and Hygiene		
When was the work published?	July 2016		
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7.1 Abstract

Although large-scale programs, like India's Total Sanitation Campaign (TSC), have improved latrine coverage in rural settings, evidence suggests that actual use is suboptimal. However, the reliability of methods to assess latrine use is uncertain. We assessed the reliability of reported use, the standard method, by comparing survey-based responses against passive latrine use monitors (PLUMs) through a cross-sectional study among 292 households in 25 villages in rural Odisha, India, which recently received individual household latrines under the TSC. PLUMs were installed for 2 weeks and householders responded to surveys about their latrine use behavior. Reported use was compared with PLUM results using Bland–Altman (BA) plots and concordance statistics. Reported use was higher than corresponding PLUM-recorded events across the range of comparisons. The mean reported "usual" daily events per household (7.09, 95% confidence interval CI = 6.51, 7.68) was nearly twice that of the PLUM-recorded daily average (3.62, 95% CI = 3.29, 3.94). There was poor agreement between "usual" daily latrine use and the average daily PLUM-recorded events (ρ_c = 0.331, 95% CI = 0.242, 0.427). Moderate agreement (ρ_c = 0.598, 95% CI = 0.497, 0.683) was obtained when comparing daily reported use during the previous 48 hours with the average daily PLUM count. Reported latrine use, though already suggesting suboptimal adoption, likely exaggerates the actual level of uptake of latrines constructed under the program. Where reliance on self-reports is used, survey questions should focus on the 48 hours prior to the date of survey rather than asking about "usual" latrine use behavior.

7.2 Introduction

Improving sanitation is regarded as a key public health measure to reduce infectious diseases.[1] Latrine use is an important outcome indicator for monitoring the effectiveness of sanitation programs.[2–4] Although large-scale campaigns in India, which prioritize the elimination of open defecation, have succeeded in increasing latrine coverage, actual adoption and use has been suboptimal.[4–9] Poor use may be a partial explanation why recent evaluations of such programs have found that they have not prevented sanitation-related diseases such as diarrhea and soil-transmitted helminth infection.[10–12] Increasing evidence has shown that in settings such as India, an emphasis on latrine access and/or ownership alone, without addressing latrine use, is not likely to yield desired programmatic outcomes, including open defecation free status, health, and other gains from sanitation.[4,8,9,13,14]

However, measuring household and individual latrine use is challenging. Direct observation is costly, potentially objectionable, and has shown to cause reactivity.[14] Spot-checks and latrine use indicators provide only an indication of household use, not individual use.[10,11,15,16] Some evidence suggests that repeated spot-checks have potential to cause reactivity in longitudinal studies.[17] Sensor-monitored use based on passive latrine use monitors (PLUMs) or similar devices are useful in assessing the reliability of other methods.[14] They have identified evidence, for example, of reactivity in using direct observation, previously thought to be the gold standard in assessing latrine use. However, existing sensors are not practical for large-scale latrine use assessment.

Self-reported measures, such as maintaining a diary[18,19] or responding to surveys,[5,20,21] are the most common method to measure behavior in water, sanitation, and hygiene interventions. The Joint Monitoring Program for Water and Sanitation (JMP), which currently monitors progress toward international water and sanitation targets, recommends that national surveys ask, "What kind of toilet facility do members of your household usually use?"[22] In India, the 69th round of the National Sample Survey included a section on "latrine," which among other items, asked "whether all household members of categories specified are using the latrine" (yes, no, not applicable). The categories were "male of age below 15 years," "male of age 15 years and above," "female of age below15 years," and "female of age 15 years and above."[9] Some studies have used the self-report method as a complementary approach in conjunction with other approaches, including technology-based measures, such as electronic soap loggers, and latrine inspections or spot-checks.[10,23]

However, evidence suggests that study subjects tend to over-report desirable behavior in response to survey questions.[3,10,24–27] Repeated interviews or completing a diary and ensuring that recordings are not missed may be burdensome to investigators and subjects, leading to fatigue and thereby reducing reliability.[28] Further, household-based surveys that are often used to elicit such information tend to be time consuming and expensive.[3]

In the context of a large-scale trial (the "Sanitation Trial") to assess the impact of improved sanitation in rural India, we undertook a few approaches to assessing latrine use.[11,14] In this article, we report on various approaches to assessing latrine use based on self-reports at the household and individual level, and compare the results with PLUMs mounted inside the latrine.

7.3 Materials and methods

7.3.1 Study context

The study was conducted among 25 villages in rural Puri, a coastal district of Odisha, India, which comprised part of the intervention arm of a randomized, controlled trial (the "Sanitation Trial") to assess the health impact of rural sanitation under the Indian Total Sanitation Campaign (TSC).[11,29] Findings from a baseline survey revealed that approximately 10% of households among the intervention villages had access to a latrine.[29] Between January 2010 and March 2011, WaterAid and its implementing partners conducted community mobilization and constructed household pour-flush latrines among eligible "below the poverty line" households.[30]

7.3.2 Village and household selection

This latrine use study was conducted among 25 of the 50 villages comprising the intervention arm in the Sanitation Trial. Villages were eligible if they had at least one household that was included in the Sanitation Trial surveillance (had a child under 4 years and/or a pregnant woman at baseline) with a functional latrine as a result of the intervention (a surrounding wall/ enclosure, a door/closure over the entrance for privacy, an unbroken toilet pan, a functional pan-pit connection, and the presence of a covered pit). A total of 46 villages were found to be eligible from which 25 were randomly selected for the latrine use study using block-level stratification and a computer-generated sequence. All surveillance households in the selected villages were eligible to participate in the latrine use study provided they had functional latrines. Eligible households were enrolled if they consented to participate in the study.

7.3.3 Surveys to assess latrine use

In this article, we compare various approaches to assessing reported use both at the household and individual level with results from PLUMs. Both these methods were pilot tested extensively in the field in 2011 and 2012 before arriving at the final versions that were ultimately used in this study. Reported latrine use was assessed by trained enumerators using a survey-based instrument translated into the local language. The survey included questions on whether the household has access to a latrine, whether they owned a latrine, whether any members of the household have "ever use(d)" the latrine since it was constructed, and whether any members of the household used any other latrine in the village. It then went on to capture latrine use data for each member of a given household, thereby enabling an assessment both at individual and household levels. This study used data obtained through three main survey questions to enable a valid comparison with concurrently obtained PLUM-recorded data for the given household: "usual" or average daily latrine use; latrine use "yesterday" (or the last day of the observation period); and latrine use the "day before yesterday" (or the second last day of the observation period). The fourth comparative category, which was latrine use in the last 48 hours of observation, was a derived measure that was a summation of latrine use "yesterday" and the "day before yesterday." These categories were selected to enable a comparative assessment of the two measures in the context of an extended perspective of use ("usual" latrine use behavior), and a more time-bound perspective of use (latrine use behavior for "yesterday," the "day before yesterday," or the last 48 hours).

7.3.4 Passive Latrine Use Monitor

The PLUM represents the fourth generation of a device described elsewhere.[14] The device was developed by Portland State University in the United States (www.pdx.edu/sweetlab). Mounted in a latrine, the battery powered device employs a passive infrared (PIR) motion sensor to detect the presence or absence of warm-body movement within its viewing range. An algorithm developed and validated based on a previous generation of the device is used to interpret the raw data and generate estimates of likely "defecation events." The algorithm distinguished likely non-defecation events as those characterized by dense motion-based triggering in the PLUM under 30 seconds with no similar triggers within 10 minutes before or after.[14]

7.3.5 Household follow-up procedure

Based on data from a sample of 30 households where the PLUM had been installed as part of a pilot study in 2011–2012, we determined a within household correlation of mean PLUM-recorded events over an average of 42 observation days per household was high (intra-class correlation coefficient = 0.38) and that repeat measurements of more than 14 days in a household per round would yield little gain in study power. We therefore selected a 2-week follow-up period. Some of the results from this survey will be reported in another paper.

PLUMs were installed in eligible household latrines for a 16-day period. Days 1 and 16 that corresponded to installation and removal dates were dropped to reduce errors. Data from the intervening 14-day period were used. If a household owned more than one latrine, PLUM devices were installed in each of those latrines. Since we found that cellular coverage was poor in the study area, we installed majority of the PLUMs in a local logging mode to ensure that data were recorded and safely stored. These data were later uploaded to a MySQL server for analysis.

Data on reported latrine use were collected for each individual household member in a given household. Questions on reported use were administered to all household members that were present and were able to comprehend and respond to queries. In the event that a household member was not present or was unable to answer the questions, the consenting female head of household or the eldest daughter-in-law was considered the primary household respondent, and provided information on latrine use for those household members. The reported latrine use survey was conducted at the start of the monitoring period (on the same day that the PLUM was installed in the household) except for two questions on the frequency of latrine use “yesterday” and the “day before yesterday,” which were administered at the end of the monitoring period (on the day that the PLUM was retrieved from the household). The frequency of latrine use was recorded only for those members currently living in the household, and visitors, if any, to ensure a more accurate estimate of the total number of household members at the time of data collection.

With regard to reported latrine use for “yesterday” and the “day before yesterday,” each reported 24-hour period was divided into four segments (sunrise/morning; pre-noon/ afternoon; evening/sunset; night), and reported events were queried during each segment for each household member to aid more accurate recall. As with the more general question regarding overall use, all household members who were present were asked to report their use and the primary household respondent was asked about latrine use of household members who were unavailable and/or unable to respond. Additionally, the respondent was asked to recall if they had visitors/non-household members on that specific day who may have used the latrine. If they did, similar latrine use data for the visitor(s) were recorded with a distinct coding for the visitor(s). This was done to increase accuracy of reported use by all individuals who may have used the latrine in the specified time.

Additionally, latrine spot-checks were conducted by trained observers as an additional means to assess latrine use in all households on the day that the PLUM was removed, that is, day 16. The four latrine spot-check indicators that were considered were 1) evidence that latrine is used as storage (where storage indicated non-use); 2) leaves/dirt in toilet pan (where the presence of leaves/ dirt indicated non-use); 3) water container in/near latrine for washing (where the presence of a water container indicated use); and 4) slippers outside or inside the latrine (where the presence of slippers indicated use).

Table 7-1 highlights the questions and methods used for assessing reported latrine use to enable a comparison with a corresponding PLUM-recorded measure for four categories. The estimation approaches used for both measures are also included.

7.3.6 Data analysis

The survey data were entered using EPI-Data 3.1 (EpiData Association, Odense, Denmark). Data were processed and analyzed using STATA 12 (StataCorp, College Station, TX)[31] and R (Version 3.1.2; R Foundation for Statistical Computing, Vienna, Austria).[32] Agreement between PLUM-recorded latrine use and reported latrine use was assessed for both the usual latrine use item and the items regarding use in the prior 48 hours as presented in Table 7-1. The comparison of average reported daily use on days 13 and 14 with the average daily PLUM-recorded count across the total monitoring period was to determine whether the more targeted recall items had better agreement with over-all usage patterns than did the more general "usual use" item.

Bland–Altman (BA) plots were constructed to assess agreement between reported latrine use and PLUM-derived count for each of the comparisons listed in Table 7-1. Because the simple BA method assumes that both the mean and standard deviation (SD) of the differences between methods are constant across the range of measurement, we used the approach suggested by Bland and Altman to assess these assumptions and constructed adjusted plots that accounted for non-constant bias and/or variance.[33] The steps in this approach were as follows:

1. Given $R_i =$ reported use in household *i* and $P_i =$ PLUM-derived use in household *i*, the difference between reported use and PLUM-derived use was calculated as $D_i = R_i - P_i$ and the average of reported use and PLUM-derived use was calculated as $Av_i = (R_i + P_i)/2$

2. The mean bias between methods was modeled using linear regression as $D_i = a + b(Av_i)$. Non-constant bias is indicated by $b > 0$

3. The absolute residuals from the model specified in step 2 were regressed on the average (Av) of the methods, $R_i = \alpha + \beta(Av_i)$. Non-constant variance (heteroscedasticity) is indicated by $\beta > 0$

4. As the absolute residuals from step 3 follow a half-normal distribution, the relationship of the standard deviation of the differences to the average of the measurements is given as $SD_i = \alpha\left(\sqrt{\pi/2}\right) + \beta\left(\sqrt{\pi/2}\right) * Av_i$. Therefore, the 95% limits of agreement for the difference between the two methods given their average

were calculated as $D_i \pm 2(SD_i)$.

The mean difference between methods and 95% limits of agreement were plotted against the average of the methods per conventional BA plot format.

Next, to model the direct relationship between reported use and PLUM count for each category of comparison, symmetric prediction equations with corresponding 95% prediction intervals were derived from the results of the BA analysis.[34] Using the parameter estimates from the previous equations, the predicted PLUM-derived count for a given value of reported use was calculated as:

$$P_i = \frac{a \pm 2\alpha}{1 - (b/2 \pm \beta)} + \frac{1 + (b/2 \pm \beta)}{1 - (b/2 \pm \beta)} * R_i$$

and predicted reported use for a given PLUM-derived count was calculated as:

$$R_i = \frac{-a \pm 2\alpha}{1 + (b/2 \pm \beta)} + \frac{1 - (b/2 \pm \beta)}{1 + (b/2 \pm \beta)} * P_i$$

Finally, the concordance correlation coefficient (CCC) was calculated for each pair of measures using the “concord” package.[35] The CCC is a standardized measure of the variation of the linear relationship between two methods from the 45° line through the origin (the line of perfect agreement). A CCC value of 1 indicates perfect concordance between the measures, whereas a value of 0 indicates a complete lack of concordance. The CCC is a more appropriate method for assessing agreement than the often used Pearson correlation coefficient as the CCC measures both precision, the deviations of the observations from the line of best fit, and accuracy, the distance of the fit line from the line of perfect agreement.[36] We generated bootstrap 95% confidence intervals (CIs) for the CCC (bias corrected accelerated based on 2,000 bootstrap replicates). To assess for significant differences in the concordance of reported use with PLUM events across the comparison categories, we generated bootstrap 95% CIs (2,000 replicates) of the difference between CCCs using the approach described by Crawford and others.[36]

With reference to the four latrine spot-check indicators, we conducted an additional series of analyses to assess whether incorporating information from the four selected latrine spot-check items reduced the observed bias in reported latrine use relative to the PLUM-recorded events. Specifically, if household members reported latrine use but the latrine spot-check item indicated non-use, the reported use for that household was given a value of 0. In households with multiple latrines, the nonuse condition needed to be met in all the latrines for the given household. The CCC and the limits of agreement from the BA plot were recalculated with the adjusted values and compared with the unadjusted reported values. This comparison was conducted independently for each of the spot-check items as well as for the combined presence of any of the indicators.

7.3.7 Ethics

The latrine use assessment research was a sub-study of the Sanitation Trial and was granted ethics approval by the Ethics Committee of the London School of Hygiene and Tropical Medicine (Approval #5561, as amended), and by the Institutional Ethics Committee of the Xavier University, Bhubaneswar (Approval #310510, as amended). The Sanitation Trial was registered with ClinicalTrials.gov (Registration No. NCT01214785). Participants in the research were provided full details of the study prior to seeking informed, written consent from the male/female head of the household. In addition, Village Water and Sanitation Committee members were also consulted prior to initiation of the study. Measures were taken to ensure confidentiality for all participants.

7.4 Results

We obtained results on latrine use from 292 households. With 14 days of surveillance data per household, the study includes a total of 4,088 days of household-level latrine use data for 2,035 individuals, including 31 visitors. The average household size was 6.74 (SD = 3.02) with a range from 2 to 29 members per household. Comparison of reported latrine use and PLUM-recorded latrine events revealed that, on average, the reported use measures were higher than the corresponding PLUM-recorded latrine events across the range of comparisons (Figure 7-1). The mean reported "usual" daily events (7.09, 95% CI = 6.51, 7.68) was nearly twice as high as that of the PLUM-recorded daily average (3.62, 95% CI = 3.29, 3.94). Reported use on days 13 and 14 were also higher than their corresponding PLUM-recorded latrine events, but that difference was markedly less. The average PLUM-recorded latrine events were similar for the 14-day observation period (3.62, 95% CI = 3.29, 3.94) and for the last 48 hours (3.59, 95% CI = 3.23, 3.95). It may therefore be reasonable to compare the PLUM-recorded daily average for the 14-day observation period with average reported use for the prior 48 hours in the fourth category. For the "usual" or average daily reported use measure, the proportion of self-report to report was 25.3% self-report, 74.7% reported. For the 48-hour recall measure, it was 24.0% self-report and 76.0% reported.

7.4.1 Assessing agreement using BA plots

In each of the four categories, the results of regressing the difference between PLUM events and reported use on their average indicated non-constant bias between the methods. Similarly, there was a significant positive relationship between the absolute residuals from the previous step and the average of the methods in each category, indicating non-constant variance between PLUM derived-use and reported use. Figure 7-2 presents the BA plot of the difference between the two methods against their average for the two main comparison categories—reported "usual" daily latrine use with average daily PLUM-recorded latrine events and the average of reported use on days 13 and 14 with average daily PLUM-recorded events during the total observation period. The BA plots comparing reported use on day 13 with PLUM-recorded events on day 13, and reported use on day 14 with PLUM-recorded events on day 14 are included in the supplementary information material (Supplemental Figure 7-4 A and B).

Across the comparisons, there was a pattern of upward bias in the difference between reported use and PLUM events, indicating that, on average, households over-reported latrine use relative to the PLUM-recorded events during the observation period. The magnitude of this difference was greatest between reported "usual" latrine use and the average household PLUM-recorded events (Figure 7-2A). The equations derived from the BA analysis indicate that reported "usual" daily use was, on average, 118% higher than the average number of PLUM events recorded in the household (Figure 7-3A). Notably, when respondents were asked about use in the households on days 13 (day before yesterday) and 14 (yesterday), the bias between reported use and PLUM events on the corresponding day was reduced (Supplemental Figures 7-4, 7-5). Across the comparison categories, the 95% limits of agreement were fairly wide.

Given the reduction in bias observed between the reported measures of daily latrine use in the prior 48 hours with the PLUM-recorded latrine events for those days, we averaged the reported use "yesterday" and the "day before yesterday" within each household and compared that to their average daily PLUM-recorded events across the 2-week observation period. As displayed in the BA plot (Figure 7-2B), the average bias between the 48-hour recall measure and the average daily PLUM-recorded events was less than that with the measure of reported "usual" latrine use. The predicted frequency of latrine use with the 48-hour recall measure was 60% higher than the average daily PLUM-recorded events over the 2-week study period (Figure 7-3B).

7.4.2 Concordance correlation coefficient

The results obtained from calculation of the concordance correlation coefficient were also found to be aligned with the results of the BA analysis. There was poor concordance between reported "usual" daily latrine use and the average daily PLUM-recorded events (ρ_c = 0.331, 95% CI = 0.242, 0.427). The concordance between reported use on day 13/the "day before yesterday" and the corresponding day's count of PLUM events was

0.467 (95% CI = 0.334, 0.560). We found that agreement further improved between reported use for day 14/"yesterday" and the PLUM count for the same 24-hour period (ρ_c = 0.581, 95% CI = 0.476, 0.688). Finally, the CCC (ρ_c = 0.598, 95% CI = 0.497, 0.683) for reported use in the last 48 hours and PLUM-recorded use over 14 days indicated an improvement in precision and a moderate agreement between the two measures. The concordance between the 48-hour recall measure and the average PLUM-recorded events was significantly higher than that between the "usual" latrine use measure and the average PLUM count (95% CI of the difference: 0.21, 0.32, $P < 0.05$).

The use of the four latrine spot-check indicators to adjust reported latrine use in households where visual inspection suggested that the latrine was not being used resulted in negligible improvements in both the CCC and the limits of agreement from the BA plot (data not shown).

7.5 Discussion

We found that average reported latrine use was consistently higher than average PLUM-recorded latrine use over all four categories of comparison considered in this study. This is consistent with previous literature, which indicates that relying on reported sanitation behavior via surveys may be subject to courtesy and recall bias and may influence the behavior being monitored.[3,27,28] Additionally, the magnitude of this observed bias was dependent on the category or type of reported latrine use measure. The largest bias was observed with the most general item that queried "usual" number of times per day that a participant used the latrine. This may be because of higher recall bias in instances when recall is not bound by a defined time, such as when responding to "usual" latrine use practices. Our results indicate that the bias was reduced with the measures that compared reported latrine use in the prior 48 hours to corresponding PLUM-recorded use during that time. A plausible explanation for this may be that when queried about latrine use behavior in the prior 48 hours, householders were asked more precise questions with references to clearly defined time. For example, they were asked to respond to each day separately, that is, reported use for yesterday and for the before yesterday. Further, each day was broken into four segments corresponding to sunrise/morning; pre-noon/afternoon; evening/sunset; night/ pre-sunrise hours, to facilitate greater accuracy of responses to these time-bound segments. Additionally, visual aids were used to facilitate the understanding of illiterate participants in the study sample. This design may have helped to reduce over-reporting for the relevant periods.

Among the categories of reported latrine use measures, agreement between reported use and PLUM-recorded events was fairly low. Although agreement between average reported use of latrine(s) over the prior 48 hours and average daily PLUM-recorded events for the 2-week period was higher than all the previous measures, it was still less than 0.6 (ρ_c = 0.598, 95% CI = 0.497, 0.683). However, it is note-worthy that reported daily use during the previous 2 days was a significantly less biased and more precise measure of average daily PLUM-recorded latrine use across the entire study period than was the more general question about "usual" latrine use. This has implications for how reported use measures are developed and administered in future studies.

It is important to note that the PLUM has not yet been established as the "gold standard" for evaluating other methods for latrine use assessment. There are limitations associated with the PLUM algorithm, which may warrant further evaluation in future studies. Although the algorithm has been refined based on previous research and subsequent small scale testing, it is limited in its ability to disambiguate latrine events that occur within short inter-arrival times.[14] Consequently, there may be an underestimation of discrete events during peak use times, although it is unlikely that this alone could account for the magnitude of the difference observed in this study. There is also a possibility of behavioral reactivity or reporting bias induced by the presence of the PLUM in the latrine, which may influence the estimation of the bias between reported and PLUM-recorded use. Moreover, the device does not definitively distinguish between the nature of latrine activities, such as the disposal of child feces, which is critical to ensuring sanitary gains,[37,38] urination, or menstrual hygiene. While estimates of average use per person per day may be derived from the aggregated household-level PLUM-recorded events, unlike the (self-) reported use measure, it does not permit a distinction between users and nonusers in a given household or help in profiling those refractory members, so that they may be targeted through further interventions.

Other limitations of this study include a relatively small sample size because of the limited number of PLUMs that were available, each of which had to be installed for a period of 2 weeks per latrine. In households that had multiple latrines, one PLUM was installed per latrine. The study was limited to only those households that were part of the intervention arm of the Sanitation Trial. Therefore, any generalizations made to the larger population would need to be done with caution. Although data were gathered synchronously by the reported use survey and the PLUM for the latrine use measures for "yesterday" and the "day before yesterday," it was not possible to do so for the "average daily use" category. It was assumed that "usual" daily reported latrine use might be comparable with PLUM-recorded latrine use counts obtained over the 2-week monitoring period. The discrepancy we observed between respondent recall of visitors in the prior 2 days, when households accounted for visitors, compared with that for the first 12 days of monitoring, when respondent recall was poor, suggests the presence of recall bias in our "usual" daily reported use data. In such cases, relying exclusively on the measure of reported use may result in an under-estimation of latrine use. There may also be a possibility of courtesy bias in respondent reporting given that the survey focused on sanitation.

Despite these limitations, this study furthers research on the methods for assessing latrine use in low-income settings and adds to a growing body of evidence on the feasibility of instrumented monitoring of sanitation behavior at the house-hold level.[14,39]

This is particularly significant in the context of latrine use assessment since such alternatives are likely to offer a viable low-cost, objective, non-invasive and medium to long-term perspective of use. Based on our study data, we may also conclude that while all the categories of reported use are biased compared with the PLUM-based measurement, the aggregated 48-hour recall of individual latrine use in households is the least biased and provides a more accurate measure of overall household latrine use than does the general recall. This measure of reported use may therefore be a useful approach to assess household-level latrine use behavior when sensor-based monitoring alternatives are infeasible.

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Disclosures: In addition to his academic appointment at Portland State University, Evan Thomas was the founder and serves as the President and CEO of Sweet Sense, Inc., which designed, manufactured, and supplied the PLUMs used in this study.

TABLE 7-1: Questions and methods used for assessing reported use of latrines and the corresponding PLUM-recorded estimation approaches for four comparison categories

Parameter	**Survey question (asked in Oriya)**	**Approach to estimate reported use**	**Corresponding PLUM-recorded estimation**
“Usual” or average daily reported latrine use	Among your family members who use the latrine, can you please tell me how many times in the day they usually use the latrine?	Average daily reported use for a given household: sum of “usual” reported latrine use per day for all latrine using household members.	Average daily PLUM-recorded use for a given household: sum of PLUM-recorded defecation events over 14 days/ 14 days (for households without any reported visitors) OR Sum of PLUM-recorded defecation events over 12 days/ 12 days (for households reporting visitors on days 13 and 14).
Reported latrine use for “yesterday” (day 14)	For each member of your household, please tell us which members used the latrine for defecation “yesterday” and the approximate time of day they used it. If they used the latrine, tell us the number of times they used it (based on four dis-aggregated parts of the day. Visual aids depicting the parts of the day and household members used to facilitate recall).	Sum of reported latrine events across all parts of the day for all household members for “yesterday” in a given household.	Sum of PLUM-recorded defecation events for the same day in the same household.
Reported latrine use for the “day before yesterday” (day 13)	For each member of your household, please tell us which members used the latrine for defecation the “day before yesterday” and the approximate time of day they used it. If they used the latrine, tell us the number of times they used it (based on four dis-aggregated parts of the day. Visual aids depicting the parts of the day and household members used to facilitate recall).	Sum of reported latrine events across all parts of the day for all household members for the “day before yesterday” in a given household.	Sum of PLUM-recorded defecation events for the same day in the same household.
Reported latrine use - 48 hour recall	No separate question asked.	Sum of total reported use for “yesterday” and the “day before yesterday”/ 2: to estimate average reported use based on prior 48 hour recall for a given household.	Average daily PLUM-recorded use for a given household based on the 14 (or 12) day monitoring period.

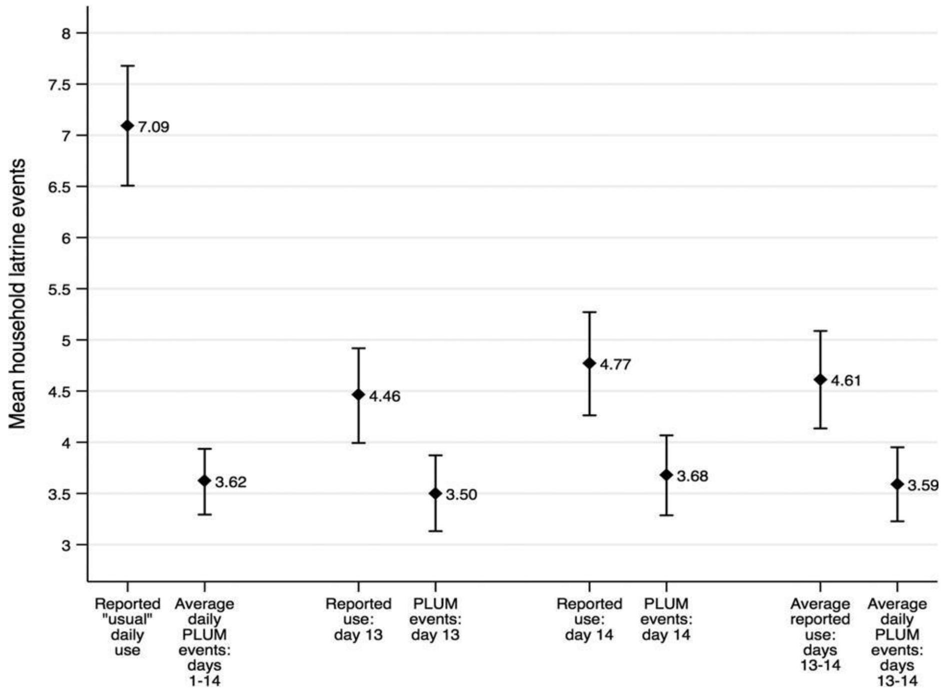


FIGURE 7-1. Mean latrine events and 95% confidence interval for households (N = 292) for reported latrine use and corresponding PLUM-recorded latrine use for varying time. The average reported use events are consistently greater than the corresponding PLUM-recorded latrine events for all four comparison categories.

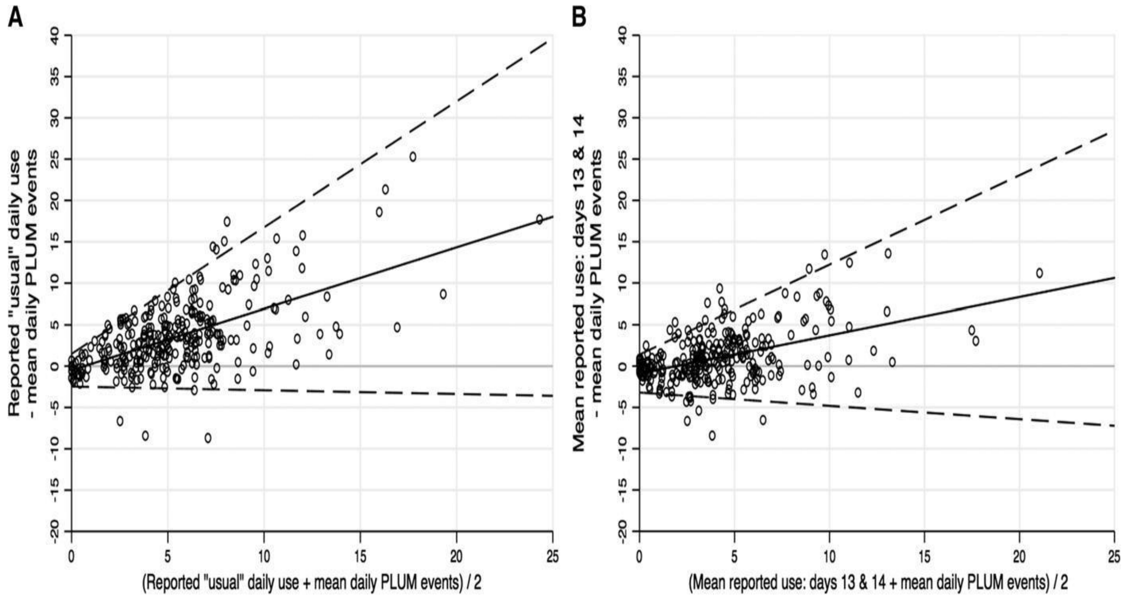


FIGURE 7-2. Bland–Altman plots comparing (A) reported "usual" daily latrine use with average daily PLUM-recorded latrine events, (B) average of reported use on days 13 and 14 with average daily PLUM-recorded events during the total observation period. The mean difference between methods (bias) is shown by the solid line and the dashed lines show the 95% limits of agreement, which is the interval expected to contain 95% of the differences between methods. For each comparison, both the mean difference and the variance between methods are observed to increase as the magnitude of the measurement increases.

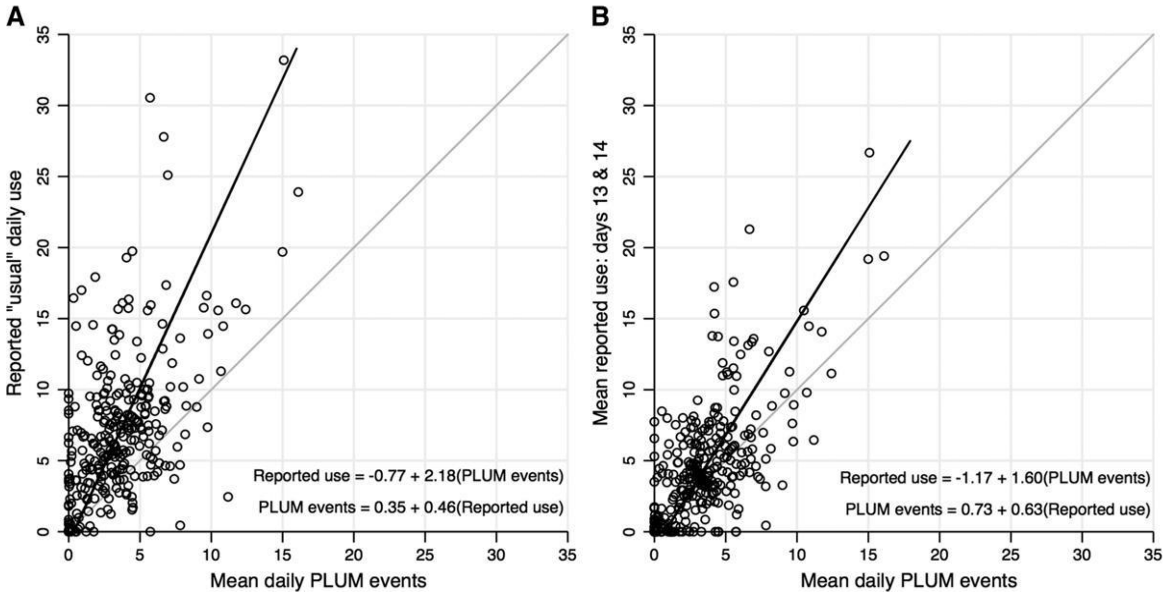
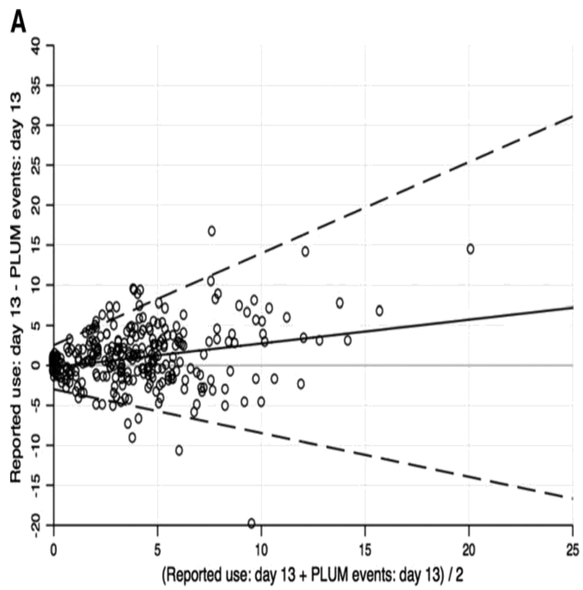
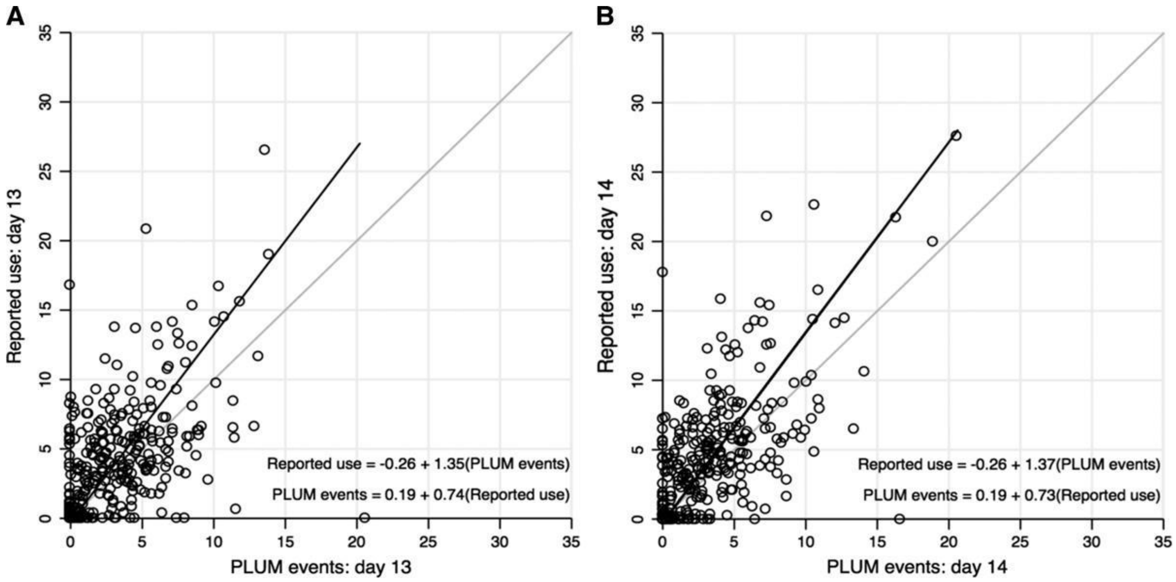


FIGURE 7-3. Scatterplots of (A) reported "usual" daily latrine use and average daily PLUM-recorded latrine events, (B) average of reported use on days 13 and 14 and average daily PLUM-recorded events during the total observation period. Symmetric prediction equations allowing for direct conversion between the methods are derived from the Bland–Altman analysis. The predicted value of one method (e.g., reported use) given the other (e.g., PLUM events) is displayed by the solid line. The shaded 45° line at the origin is the line of equality, indicating perfect agreement between the methods.



SUPPLEMENTAL FIGURE 7-4. Bland–Altman plots comparing (A) reported use on day 13 with PLUM-recorded events on day 13, (B) reported use on day 14 with PLUM-recorded events on day 14. The mean difference between methods (bias) is shown by the solid line and the dashed lines show the 95% limits of agreement, which is the interval expected to contain 95% of the differences between methods. For each comparison, both the mean difference and the variance between methods are observed to increase as the magnitude of the measurement increases.



SUPPLEMENTAL FIGURE 7-5. Scatterplots of (A) reported use on day 13 and PLUM-recorded events on day 13, (B) reported use on day 14 and PLUM-recorded events on day 14. Symmetric prediction equations allowing for direct conversion between the methods are derived from the Bland–Altman analysis. The predicted value of one method (e.g., reported use) given the other (e.g., PLUM events) is displayed by the solid line. The shaded 45° line at the origin is the line of equality, indicating perfect agreement between the methods. In Figure 2A, reported use was, on average, 35% higher than recorded PLUM events on day 13 and in Figure 2B, it was 37% higher than recorded PLUM events on day 14.

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Student	Antara Sinha
Principal Supervisor	Thomas F. Clasen
Thesis Title	Assessing latrine use in low income countries: a field study in rural India

If the Research Paper has previously been published please complete Section B, if not please move toSection C

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SECTION C – Prepared for publication, but not yet published

Where is the work intended to be published?	International Journal of Hygiene and Environmental Health
Please list the paper's authors in the intended authorship order:	Antara Sinha, Corey L. Nagel, Wolf P. Schmidt, Belen Torondel, Sophie Boisson, Parimita Routray, Thomas F. Clasen
Stage of publication	**Submitted**

SECTION D – Multi-authored work

For multi-authored work, give full details of your role in the research included in the paper and in the preparation of the paper. (Attach a further sheet if necessary)	With guidance from my advisors, I developed the study design, wrote the research protocol, managed data collection and entry, cleaned the data, performed the analyses, and wrote all drafts of the paper. All co-authors provided comments on the draft article, many of which I incorporated during revisions to

	the article.

Student Signature: ______________________ **Date:** 1 September 2016

Supervisor Signature: ______________________ **Date:** 1 September 2016

8.1 Abstract

Introduction: Monitoring of sanitation programs is often limited to sanitation access and coverage, with little emphasis on use of the facilities despite increasing evidence of widespread non-use.

Objectives: We assessed patterns and determinants of individual latrine use over 12 months in a low- income rural study population that had recently received latrines as part of the Government of India's Total Sanitation Campaign (TSC) in coastal Puri district in Odisha, India.

Materials and methods: We surveyed 1938 individuals (>3 years) in 310 rural households with latrines from 25 villages over 12 months. Data collection rounds were timed to correspond with the seasons. The primary outcome was reported use by each member of the household over the prior 48 hours. We classified use into three categories—"never", "sometimes" and "always/usually". We also assessed consistency of use over six days across the three seasons (dry cold, dry hot, rainy). We explored the association between individual and household-level variables and latrine use in any given season and longitudinally using multinomial logistic regression. We also inquired about reasons for non-use.

Results: Overall, latrine use was poor and inconsistent. The average response probability at any given round of never use was 43.5% (95% CI = 37.9, 49.1), sometimes use was 4.6% (95% CI = 3.8, 5.5), and always/usual use was 51.9% (95% CI = 46.2, 57.5). Only two-thirds of those who reported always/usually using a latrine in round one reported the same for all three rounds. Across all three rounds, the study population was about equally divided among those who reported never using the latrine (30.1%, 95% CI = 23.0, 37.2), sometimes using the latrine (33.2%, 95% CI = 28.3, 38.1) and always/usually using the latrine (36.8%, 95% CI = 31.8, 41.8). The reported likelihood of always/usually versus never using the latrine was significantly greater in the dry cold season (OR = 1.50, 95% CI = 1.18, 1.89, p = 0.001) and in the rainy season (OR = 1.34, 95% CI = 1.07, 1.69, p = 0.012), than in the dry hot season.

Across all three seasons, there was increased likelihood of always/usually and sometimes using the latrine versus never using it among females and where latrines had a door and roof. Older age groups, including those aged 41-59 years and 60+ years, and increase in household size were associated with a decreased likelihood of always/usually using the latrine versus never using it. The leading reason for non-use was a preference for open defecation.

Conclusion: Results highlight the low and inconsistent use of subsidized latrines built under the TSC in rural Odisha. This study identifies individual and household levels factors that may be used to target behavior change campaigns to drive consistent use of sanitation facilities by all.

8.2 Introduction

Sanitation is considered to be fundamental to human health (WHO, 2014b). Yet many people, especially those in low-resource settings, have no access to sanitation. Among an estimated 946 million who practice open defecation, nine in ten of those reside in rural settings (WHO-UNICEF, 2015). Almost 60% of the world's open defecators live in India, most in rural settings (Planning Commission, 2013, WHO-UNICEF, 2014a).

By 2016, the Central Indian Government's sanitation programs have already been operational for more than three decades (Planning Commission, 2013). The Total Sanitation Campaign (TSC)—the version of the program which is investigated here—was launched in 1999 as part of a comprehensive program aimed to accelerate sanitation coverage in rural areas and make India open defecation free (ODF or '*Nirmal Bharat*') by 2017. It focused primarily on the construction of individual household pit latrines. The TSC was designed as a "demand-driven, community-led", "low to no subsidy" approach to total sanitation and was implemented by the state governments (DDWS, 2011).

In the decade of the TSC through March 2010, 64.3 million individual household latrines were reportedly constructed, including 34.8 million latrines in below poverty line households (WSP, 2011a). However, a review of the TSC commissioned by the Government of India (GoI) suggested that as many as 72.63% households in rural India practice open defecation even though they have access to latrines (Planning Commission, 2013). This estimate, although higher than others (WHO-UNICEF, 2014a), reveals that latrine access does not always translate into use (Sanan and Moulik, 2007, WSP, 2011a, National Sample Survey Office, December 2013). It offers insights into likely reasons for open defecation, even among households that have latrines, including that it is “an established age old practice” with little or no stigma attached to it (Planning Commission, 2013, Coffey et al., 2014, Ghosh and Cairncross, 2014), and generally low awareness of improved hygiene behavior (Banerjee and Mandal, 2011, Planning Commission, 2013). Finally, the scale of the problem reflects the relatively low development priority accorded to the sector (WSP, 2011a, Ghosh and Cairncross, 2014). From a monitoring perspective, it implies that the focus should also be on latrine use rather than only on access and coverage.

Monitoring progress on sanitation has been greatly influenced by the approach adopted by the WHO-UNICEF Joint Monitoring Program for Water Supply and Sanitation (JMP). JMP sanitation monitoring focuses on coverage—the percentage of the population with access to improved sanitation facilities, i.e., flush or pour flush to piped sewer systems, septic tanks or pits; ventilated improved pit (VIP) latrines; pit latrines with slabs; or composting toilets (WHO-UNICEF, 2015). While monitoring use was considered in connection with the development of the post-2015 Sustainable Development Goals (SDG), the SDG Target 6.2 continues to address only coverage and not use(WHO-UNICEF, 2014b, WHO-UNICEF, October 2015).

Similarly, the Indian government’s routine monitoring system for the rural sanitation sector is limited to periodic tracking of inputs (budget spent) and outputs (latrines constructed). It does not track actual use of latrines (Ganguly, 2008, WSP, 2013, Planning Commission, 2013). Outcomes such as ODF communities are monitored to a limited extent through the "*Nirmal Gram Puraskar"* (NGP or Clean Village Prize) verification process but latrine use data is not available in the public domain and there is little effort to track sustainability in NGP-winning local governments (WSP, 2013). As a result, implementers are incentivized to prioritize latrine construction over use or sustainable behavior change (Wicken, 2008, WSP, 2013). The consequence, according to some experts, is that the program has been reduced to "a no-gain toilet construction scheme….where India built millions of toilets but people (did) not use them" (Jitendra et al., 16-31 January 2014).

Ensuring that populations with access to latrines actually use them requires an insight into the determinants of use (O'Reilly and Louis, 2014). Research into the successful adoption and sustained use of latrines has revealed a range of factors that may potentially influence use, with health considerations only playing a minor role (Jenkins and Cairncross, 2010, Mara et al., 2010). Research suggests that a "prestige, well-being or situational drive" is required to motivate for latrine adoption and that it may vary with gender, age, occupation, life-stage, travel experience, education, wealth and income, and the physical and social geography of the village environment with reference to the availability of good defecation sites around the home and/or villages (Jenkins and Curtis, 2005, Jenkins and Cairncross, 2010). Other factors that may be associated with latrine use include family size (O'Loughlin et al., 2006), privacy and safety for women and girls (Arnold et al., 2010), a preference for open defecation even among latrine owning households, especially those that received government subsidies for latrine construction versus those that did not (Coffey et al., 2014, Routray et al., 2015), socio-economic status of the household and female literacy rates (Ghosh and Cairncross, 2014), access to water, supply-related and structural issues related to latrine construction (ICRA, April 2011, Barnard et al., 2013, Jenkins et al., 2014).

Measuring latrine use, at both household and individual levels, is challenging and a robust indicator for the same is not yet readily available for integration into large-scale household surveys (Bartram et al., 2014, Coffey and Spears, 2014). Despite certain limitations (Curtis et al., 1993, Schmidt and Cairncross, 2009, Zwane et al., 2011), self-report measures, such as a diary or survey, are popular measures of behavior assessment at both household and individual levels. Based on the results of a previously published study (Sinha et al., 2016), which compared various categories of reported latrine use and corresponding sensor-based latrine events, a reported latrine use measure of recall over the previous 48 hours has been considered in this study.

The aim of this research is to assess patterns and determinants of individual latrine use over 12 months in a low income rural study population that had recently received latrines as part of the TSC in coastal Puri district in Odisha, India.

8.3 Materials and methods

8.3.1 Study context

We conducted the study among 25 villages in rural Puri, a coastal district of Odisha, India, that comprised part of the intervention arm of a randomized, controlled trial (the “Sanitation Trial”) to assess the health impact of rural sanitation under the Indian TSC (Clasen et al., 2012a, Clasen et al., 2014). WaterAid and its partner NGOs conducted community mobilization and constructed pour-flush latrines among eligible “below the poverty line” households between January 2010 and March 2011.

8.3.2 Study design

The study followed a longitudinal design, with repeated follow up of the same population over a period of 12 months. This study design allowed us to explore the patterns of latrine use – the extent to which latrine use varied over seasons (dry hot, dry cold and rainy season), whether use was consistent - and the determinants of use.

8.3.3 Village and household selection

The sampling frame comprised 50 villages, spread across seven Blocks (district sub-divisions comprising several villages), which were part of the intervention arm in the Sanitation Trial. Villages were eligible for inclusion if they had at least one household that was enrolled in the Sanitation Trial surveillance (had a child under four years and/or a pregnant woman at baseline) with a constructed latrine as a result of the intervention. Of the 46 villages that were found to be eligible, 25 were randomly selected for this latrine use study using Block-level stratification and a computer-generated sequence. All surveillance households in the selected villages were eligible for inclusion in the study provided they had latrines. Eligible households were enrolled if they gave informed consent to participate in the study.

8.3.4 Measuring use

Our primary measure of individual latrine use was reported use by each member of the household over the prior 48 hours. Our use of 48-hour recall is based on our previous work suggesting that it may be the most reliable measure of assessing use via surveys (Sinha et al., 2016). We used a comprehensive survey-based tool that asked about place of defecation and latrine use for each household member listed in the household roster. The survey was developed after extensive pilot testing in the field in 2011 and 2012. All the survey-based instruments used in this research were translated into the local language and the fieldwork was carried out by trained enumerators in 2012-2013. Reported latrine use data was gathered for each household member (ascribed a code) in all enrolled households in each of the three seasons, that is, dry cold, dry hot and rainy season. Individual members, if present and able to comprehend and respond to the questions, were directly queried about their latrine use behavior. If a household member was absent but still currently living in the household or was unable to respond to the questions, the primary household respondent, that is, the consenting female head of household or the eldest daughter-in-law, was asked to respond on his/her behalf.

The 48-hour data was gathered by asking about latrine use “yesterday” and the “day-before yesterday”. Each reported 24 hour period was also divided into four segments (Sunrise/Morning; Pre-Noon/Afternoon; Evening/Sunset; Night). Reported events were queried during each segment for each household member to aid more accurate recall. A recording of whether the response was reported or self-reported was made for each household member.

In order to provide information that may be more useful for programmatic and policy purposes, we classified latrine use into three categories—“never”, “sometimes” and “always/usually”—based on the previous 48 hour reported use measure. Based on the results of a previously published study of defecation frequency in this region (Manas Kumar et al., 2013) and an analysis of pilot data collected during the Sanitation Trial, a conservative assumption was made that in this rural context, each person per household is likely to defecate at least once per day and at least two or more total events over the prior 48 hours. Individuals that did not use the latrine on both days were considered “never” or non-users. To qualify as a “sometimes” user, the individual must have used the latrine at least once on either of the two days. To be included in the “always/usually” use category, individuals were expected to have used the latrine at least once on both days.

In order to examine the consistency of latrine use over time, we constructed a longitudinal measure of latrine use from participants’ responses to the 48 hour recall measure at each study round. The longitudinal use measure was defined by the following criteria: “never use” included those with 0 events on both days per round resulting in 0 events over all 6 days; “always/usually use” was defined as ≥ 1 event per day per round resulting in ≥ 6 events over all 6 days; and “sometimes use” was defined as atleast 1 event on any day in any of the 3 rounds with total events > 0 but <6 across the 6 days of queried use.

The survey also gathered additional household and individual level reported latrine use data, including the reasons given by the primary household respondent or non-using household members themselves, if present, for not using the latrine despite having access to one. Survey items regarding non-use of latrines were drawn from previous research (Banda et al., 2007, WSP, 2011a, ICRA, April 2011) and a pilot study conducted in the early stages of research. Respondents were permitted to report multiple reasons for non-use, as applicable.

8.3.5 Predictor variables

The aforementioned survey also gathered data on covariates that may be associated with latrine use, including individual and contextual predictors, such as, age, gender, educational attainment, household size, demographic and socio-economic status (SES) of the household; and latrine construction and functionality status.

The gender and age of each member currently living in the household was recorded in each round of data collection. Based on evidence from previous research (WSP, March 2015) and a pilot study, which suggests that individuals of age three and below are not likely to use the latrine, we excluded this age group from our model. Age, modelled as a categorical variable, was grouped into the following quartiles: 4-12 years, 13-20 years, 21-40 years, 41-59 years, 60+ years. The ranges were chosen to capture potential variations in latrine use habits and practices, the ability to use the latrine and whether they were ambulatory or not (Routray et al., 2015). In this survey, we assessed household size in each round of data collection. Information on specific socio-economic variables was gathered only once for each study household. Educational attainment of the head of household and the primary care provider was modelled as a categorical variable (dichotomized as not completed primary school versus completed primary school). Data was gathered on the status of the household as a scheduled caste or scheduled tribe (SC/ST) and was dichotomized as yes or no. Asset ownership was recorded for each household. An asset index including watch/clock, pressure cooker, telephone, refrigerator, chair, mattress, cot, table, electric fan, sewing machine, water pump, scooter, animal drawn cart, thresher and tractor was constructed by calculating the tetrachoric correlation coefficients for the binary variables and then applying PCA to the resulting correlation matrix (Howe et al., 2012, Vyas and Kumaranayake, 2006) The first component, explaining 57.7% variance of the items was used in the analysis. Study households were divided into five wealth quintiles based on their asset index, where quintiles 1 and 5 corresponded to the lowest and highest levels respectively.

We assessed latrine construction and functionality for each household in each season or round of data collection by directly inspecting the latrine and documenting the status of features such as type of latrine, height and type of latrine enclosure, presence and type of latrine closure over entrance, presence and type of latrine roof, floor material around pan, pan condition, the number of pits per latrine, and for each pit, as relevant, the height of the pit, condition of the pit cover and the pan-pit pipe connection. If a household had more than one latrine, each latrine was examined following the same parameters. Latrines were considered to be minimally functional if they met all the following criteria: pan that is not broken/choked/ blocked; latrine pit (shared or independent); pit covering; and a pan-pit connection that is functional. In the model, we considered structural variables, including latrine wall/ enclosure of at least four feet or more, a door/closure over the entrance for privacy, and the presence of a roof, separately to assess the impact of each of these covariates on latrine use.

The latrine-house and latrine-water source distances were calculated based on the Global Position System (GPS) location of every house, their latrine(s) and the reported water source used by the given household for ablution. While data was gathered in each round of data collection, for the purpose of this study, we have only considered GPS-based distance data from one round.

Data was entered using EPIData 3.1 (EpiData Association, Odense Denmark).

8.3.6 Data analysis

We examined the association between individual and household-level variables and latrine use using multinomial logistic regression. The regression analysis was done in two stages. First, we regressed the categorical measure of latrine use in the prior 48 hours on all hypothesized determinants of use. Because data collection rounds were timed to correspond with the seasons, this model contained a categorical indicator of the season in which the measurement occurred. Next, we assessed the determinants of consistent use over the 12 month study period by regressing the latrine use measure derived from reported use across all three rounds on the same group of covariates. Models were fit with never use specified as the reference category in order to examine covariate effects on sometimes versus never use and always versus never use. Additional contrasts between outcome categories (e.g. always use versus sometimes use) were derived from fitted models using the *listcoef* command available in the SPost13 package (Long and Freese, 2014). The coefficients from all models were exponentiated to yield multinomial odds ratios, which are interpreted as the effect of a unit increase in the covariate on the odds of being in the specified outcome category rather than the reference category. In addition, we used marginal standardization to calculate the population-averaged predicted probabilities of use at specified covariate values (Muller and MacLehose, 2014). We adjusted the standard errors and 95% confidence intervals of the coefficient estimates using robust standard errors to account for the clustered structure of the data. Consistent with current recommendations, we adjusted for the highest level (villages) of clustering (Bottomley et al., 2016). In order to assess for potential bias due to a small number of higher-level clusters, we conducted sensitivity analyses adjusting for the next level of clustering, household-level with more than 300 clusters, and obtained comparable results. All analyses were conducted using Stata 14 (StataCorp, 2015).

8.3.7 Ethics

The latrine use assessment research was a sub-study of the Sanitation Trial and was granted ethics approval by the Ethics Committee of the London School of Hygiene and Tropical Medicine (Approval #5561, as amended) and by the Institutional Ethics Committee of the Xavier University, Bhubaneswar (Approval 310510, as amended). The Sanitation Trial was registered with ClinicalTrials.gov (Registration No. NCT01214785). Surveys and observations were undertaken only after obtaining informed, written consent from the male/female head of the household.

8.4 Results

8.4.1 Sampled population

The sampled population included in this study comprised 25 villages in Puri district. Of a total of 323 eligible households, 13 were excluded from analysis, including three that did not consent to participate in the study, three that had incompletely constructed latrines through the duration of the study, four where the study tools were vandalized and three with missing data on one of the household level covariates across all rounds of data collection. The analysis is based on data from a total of 1938 individuals living in 310 households. The sample excluded 266 individuals aged three years and below. Table 8-1 provides information on the characteristics of the study households and latrines at baseline. The analysis for the longitudinal measure of latrine use included 1178 individuals who were present in all three rounds.

8.4.2 Patterns of latrine use

Individual reported use in the study population was classified into “always/usually”, “sometimes” and “never” use. Derived from the regression model, the average response probability at any given round of never use was 43.5% (95% CI = 37.9, 49.1), sometimes use was 4.6% (95% CI =3.8, 5.5), and always/usually use was 51.9% (95% CI = 46.2, 57.5). The model with the outcome defined as a longitudinal consistency of use measure (considering all three rounds/seasons) estimated the average response probability of never use as 30.1% (95% CI = 23.0, 37.2), sometimes use as 33.2% (95% CI = 28.3, 38.1), and always/usually use as 36.8% (95% CI = 31.8, 41.8). Descriptive statistics comparing the outcome measure in round one with that across all three rounds revealed that of those who reported that they always/usually used the latrine in round one, 66.6% were found to also report always/usually using it across all three rounds while 33.4% reported sometimes using it. Similarly, of those who reported never using the latrine in round one, 73.4% remained in the never use category and 26.6% reported sometimes using it when all three rounds were considered.

The results of the multinomial regression (Table 2) indicate a seasonal variation in reported individual latrine use behavior. Latrine use in the dry hot season was considered the reference group. In the dry cold season, the reported likelihood of always/usually versus never using the latrine was significantly greater than in the dry hot season (OR = 1.50, 95% CI = 1.18, 1.89, p = 0.001). The predicted probability of always/usual latrine use was 55.6% in the dry cold season and 47.4% in the dry hot season, an absolute increase of 8.2% (95% CI = 3.4, 13.0, p = 0.001). Conversely, we observed an absolute reduction of 7.1% (95% CI = 2.8, 12.6, p = 0.001) in the probability of never using a latrine during the dry cold season (40.5%) compared to the dry hot season (47.7%). The evidence also indicates that in the rainy season individuals were significantly more likely to report always/usually using the latrine versus never using it in comparison to the dry hot season (OR = 1.34, 95% CI = 1.07, 1.69, p = 0.012). The predicted probability of always/usual latrine use in the rainy season was 52.8%, an absolute increase of 5.6% (95% CI = 1.0, 9.7, p = 0.016), while the probability of never use during the rainy season (42.1%) was decreased by 5.4% (95% CI = 1.2, 10.1, p = 0.014) compared to the dry hot season. There were no observed seasonal differences in the probability of sometimes use.

8.4.3 Determinants of latrine use

8.4.3.1 Determinants of latrine use in any given season

Table 2 presents the results of multinomial logistic regression models of the association between reported individual latrine use (classified as "always/usually", "sometimes" and "never") in any given season and hypothesized predictors of use.

Gender. In the analysis, females were significantly more likely than males to report always or usually using the latrine versus never using it (OR = 2.24, 95% CI = 1.87, 2.68, p < 0.001). They were also significantly more likely than males to report sometimes using the latrine versus never using it (OR = 1.99, 95% CI = 1.48, 2.70, p < 0.001).

Age. While exploring the effect of age on latrine use, the reference group was age group 21 - 40 years. There was some evidence to suggest that the age group 4-12 years had a 58% increased likelihood of sometimes versus never using the latrine (OR = 1.58, 95% CI = 1.10, 2.27, p = 0.014) but a 43% decreased likelihood of always/usually using the latrine versus sometimes using it (OR = 0.57, 95% CI = 0.41, 0.78, p < 0.001). The age group 41-59 years was found to be significantly less likely than the reference group to always/usually use the latrine versus never using it (OR = 0.68, 95% CI = 0.53, 0.89, p = 0.004) and also always/usually use the latrine versus sometimes using it (OR = 0.66, 95% CI = 0.44, 0.97, p = 0.036). The oldest age group, comprising individuals who were 60+ years, were significantly less likely to both always/usually use the latrine versus never using it (OR = 0.56, 95% CI = 0.43, 0.73, p < 0.001) and sometimes use the latrine versus never using it (OR = 0.53, 95% CI = 0.30, 0.93, p = 0.028) when compared to the reference group.

Scheduled caste/tribe. There was no evidence of an association between members of scheduled caste/ tribe (SC/ ST) always/usually using the latrine versus never using it ($p = 0.143$) or always/usually using it versus sometimes using it ($p = 0.864$) compared to non-SC/ST members. There was some evidence of SC/ST members reporting a decreased likelihood of sometimes using the latrine versus never using it.

Education. There was no evidence of an association between the educational attainment of the head of the household and reported latrine use, when comparing always/usual use of the latrine versus never ($p = 0.164$), when comparing use of the latrine sometimes versus never ($p = 0.245$), or when comparing always/usual use versus sometimes ($p = 0.598$). Similarly, the results also suggest no association between the educational attainments of the primary care giver and reported latrine use behavior, when comparing always/usual use with never ($p = 0.095$), use sometimes with never ($p = 0.965$), and always/ usual use with sometimes ($p = 0.248$).

Household wealth. There was no evidence of an association between household wealth quintile (with quintile 1, the poorest, as the reference group) and the categories of reported latrine use.

Household size. There was evidence that members living in larger sized households were significantly less likely to report always/usually using the latrine versus never using it (OR = 0.92, 95% CI = 0.87, 0.97, $p = 0.003$). Persons in larger sized households were also significantly less likely to report sometimes using the latrine versus never using it (OR = 0.87, 95% CI = 0.83, 0.91, $p < 0.001$). There was no evidence of an association between always/usual use of the latrine versus sometimes and household size ($p = 0.069$).

Distance to water supply and house. There was no evidence of an association between any of the reported latrine use categories and the distance between the latrine and water source used for cleansing purposes. Similarly, there was no evidence of an association between any of the reported latrine use categories and the distance between the latrine and the house.

Latrine construction. There was no evidence that latrine wall height or an enclosure of at least four feet or more was associated with any of the categories of reported latrine use. By contrast, the presence of a latrine door/closure significantly increased the likelihood of household members reporting always/ usually using the latrine versus never using it (OR = 3.08, 95% CI = 1.80, 5.28, $p < 0.001$) and also sometimes versus never using it (OR = 2.92, 95% CI = 1.30, 6.58, $p < 0.010$). There was also evidence that the presence of a latrine roof significantly increased reported always/usual use of the latrine versus never use (OR = 2.00, 95% CI = 1.30, 3.09, $p < 0.002$) and also sometimes versus never using it (OR = 2.92, 95% CI = 1.77, 4.83, $p < 0.001$).

Latrine functionality. Latrines were considered minimally functional if the latrine met all the criteria of an un-broken and un-blocked pan, the presence of a pit (shared or independent), a pit covering and a functional pan-pit connection. Individuals that did not have even one minimally functional latrine were found to be significantly less likely to report always/usually versus never using the latrine (OR = 0.28, 95% CI = 0.13, 0.61, $p < 0.001$) or even sometimes using the latrine versus never using it (OR = 0.27, 95% CI = 0.08, 0.92, $p = 0.037$) when compared to individuals in households that had access to at least one minimally functional latrine. There was also some evidence that those who had two minimally functional latrines were significantly more likely to report both always/usually using the latrine versus never using it (OR = 2.35, 95% CI = 1.34, 4.13, $p = 0.003$) and sometimes using the latrine versus never using it (OR = 2.10, 95% CI = 1.03, 4.28, $p = 0.041$) in comparison to the reference group.

8.4.3.2 Determinants of consistent latrine use (across all three seasons)

Table 3 shows the association between the a priori selected covariates and consistent individual latrine use.

Gender. The evidence suggests that gender remains a significant predictor of the categories of consistent latrine use where females were significantly more likely than males to report always/usual use of the latrine versus never use, sometimes use of the latrine versus never use, and also always/ usual use of the latrine versus sometimes use.

Age. It may be inferred that the two oldest age groups, that is, individuals aged 41-59 years and individuals who were 60+ years, were significantly less likely to report always/usually using the latrine consistently versus never using it and always/usually using the latrine consistently versus sometimes using it in comparison to the age group 21-40 years.

Household size. The results indicate that an increase in household size was significantly associated with a decreased likelihood of reported consistent always/usual use of the latrine versus never use.

Latrine door and roof. The evidence suggests that the presence of a latrine door/closure significantly increased the likelihood of household members reporting consistent always/usual use of the latrine versus never use and also consistent sometimes versus never use. There was also evidence that the presence of a latrine roof significantly increased reported consistent always/usual use of the latrine versus never use and also consistent sometimes versus never use.

There was no evidence of an association between SC/ST, education, SES, distance between latrine and house, distance between latrine and water source, latrine wall, the number of minimally functional latrines and reported consistent always/usually versus never use of the latrine.

8.4.4 Reported reasons for non-use of latrines

When households (N = 266) were queried on the likely reasons for non-use of latrines despite having access to facilities (Figure 1), respondents from 80.1% households suggested that they preferred open defecation; 32.3% cited other reasons that were not among those listed in the survey; 11.3% felt that an un-finished latrine building prevented them from using it; and 7.9% and 2.6% gave distance of latrine from water source and distance between the latrine and house respectively as their main reasons for not using it. Furthermore, respondents from 2.3% of households reported that the latrine getting busy during peak use hours was among their reasons for not using the facility. Respondents from only 1.5% of households attributed non-use of the latrine to the perception that it is a facility to be exclusively used by women. Factors such as the hassle of cleaning and maintaining the facility as well as lack of privacy were not reported as likely reasons for non-use of latrines.

8.5 Discussion

A few major observations emerged from monitoring individual latrine use in a rural coastal population in Odisha, India. First, individuals living in households with access to latrines do not all use the facilities, suggesting that latrine coverage does not necessarily translate into use. Second, we observed seasonal variation in latrine use in the study sample, implying that individuals do not consistently use the facilities throughout the year. Third, based on our data, we found that certain individual and household-level variables were significant predictors of individual latrine use, both when assessed in any given season or longitudinally. Fourth, among the cited reasons for non-use of household latrines, we found that a preference for open defecation was the predominant stated reason for not using the facility.

If the ideal may be assumed to be the use of a sanitation facility by all members of a household (including men and women, boys and girls, elderly, people with disabilities) whenever needed (WHO-UNICEF, 2014b, WHO-UNICEF, October 2015), we found evidence to suggest that latrine use is low in the study population. The study findings revealed that the average response probability of never using the latrine in the prior 48 hours was 43.5% when assessed in any given season. The probability decreased to 30.1% when a longitudinal latrine use measure was considered. The latter individual level estimate is similar to the 37% reported in another study conducted in the same region (Barnard et al., 2013) but is greater than seen elsewhere in India (Coffey et al., 2014). Strikingly, our data also suggests a decrease in the average response probability of individuals who report always/usually using the latrine from 51.9%, when assessed in any given season, to 36.8%, when assessed longitudinally. This finding underscores the challenge in ensuring latrine use, which is also consistent and sustained, regardless of widespread subsidized latrine construction efforts spearheaded by the government in the region. Our findings resonate with messaging from other studies (Clasen et al., 2014, Patil et al., 2014, Coffey et al., 2014) that latrine coverage and access does not always translate into latrine use or meaningful reductions in open defecation. This issue presents a key challenge to the Government's sanitation program and merits strategic and immediate action if sanitation targets are to be met.

Our analysis revealed that season was significantly related to latrine use. After adjusting for socio-demographic and latrine characteristics, the odds and average probability of always/usually using a latrine versus never were greater in the winter and rainy season than in the summer. Increased latrine use in the winter months may be attributed to various reasons including, the early morning and late evening winter chill that acts as a deterrent to open defecation; longer nights in winter and related concerns about safety in venturing too far from the house; the fields are inaccessible during the rice growing season (approximately September – January) (Routray et al., 2015). Previous research also points to the seasonal availability (or lack thereof) of open defecation sites as a partial explanation for the observed variations in latrine use. It has been suggested that open defecation is typically most challenging in the rainy season as fields and low-lying land are inundated with water, there are fears of insect and snake bites, and defecating on raised land along the road is inconvenient (Routray et al., 2015, ICRA, April 2011). In contrast, the summer months, particularly the initial months, tend to be more conducive to open defecation as crop harvesting is complete and the fields are once again clear; the weather is pleasant both early in the morning and late in the evening (Routray et al., 2015).

Gender, age, household size, latrine door and latrine roof were associated with both the 48 hour recall measure and the longitudinal or consistent measure of latrine use, while level of education was not.

Among the non-health issues that act as drivers for the adoption and use of sanitation facilities at the household-level, gender plays an important role (Coffey et al., 2014, Arnold et al., 2010). This view is corroborated by our study findings where gender was found to be a strong predictor of individual latrine use. Access to sanitation facilities, particularly individual household latrines, has been found to lower the risk of violence and sexual abuse among women and enables them to deal with defecation, menstrual hygiene and pregnancy safely and discreetly (Arnold et al., 2010, Fisher, 2006). It permits women to defecate when the need arises as opposed to following a "schedule" of early morning or late evening/night visits to the fields (Routray et al., 2015). The resulting time and energy savings from using a household latrine is thought to free up more time that may be spent on "child care, domestic hygiene, increased rest time and community development work" (Pearson and Mcphedran, 2008).

Broadly, our findings suggest that the likelihood of reportedly never (compared to always) using the latrine (and presumably, defecating in the open) increases with age, with the most notable rise among the 60+ year age group. These results mirror those from another north-Indian study where open defecation rates increased sharply among individuals who were about 60 years or above (Coffey et al., 2014). It may be because this generation belongs to a cohort where open defecation in India was even more wide-spread than it is today and they are un-willing to re-habituate themselves to use a latrine (Routray et al., 2015, O'Reilly and Louis, 2014). Further, this age-group has a relatively higher social status with fewer inhibitions about enacting their preferences (Routray et al., 2015, Coffey et al., 2014).

As expected, structural features of the latrine, such as a door/closure over entry and a roof appear to be significant predictors of individual latrine use. This finding is consistent with previous evidence that suggests that latrine structures that are functional, perceived to be more durable and robust are also more likely to be used (Barnard et al., 2013, Planning Commission, 2013, ICRA, April 2011).

Among the predictors that were not significantly associated with individual latrine use, educational attainment of the household head and the caregiver appears to be counter-intuitive. Despite previous evidence to the contrary (O'Loughlin et al., 2006, Ghosh and Cairncross, 2014), a plausible explanation for this finding may be that until the intervention was introduced, less than 10% households had access to a latrine (Clasen et al., 2012a). It may be inferred that the normative behavior in this region was open defecation. Since un-learning an “established age-old practice” that has little or no stigma attached to it (Banda et al., 2007, Planning Commission, 2013, Coffey et al., 2014, Ghosh and Cairncross, 2014) is likely to be challenging, there may be a time lag before awareness levels increase and educational attainment begins to effect sanitation behavior. Other predictors that were not significantly associated with individual latrine use were the distances between the latrine and house and the latrine and water source. It is often asserted that the post defecation practice of washing in India and flushing deems access to water as an important pre-condition to latrine use (ICRA, April 2011, O’Reilly and Louis, 2014). However, other evidence (Coffey et al., 2014, Desai and Vanneman, 2016) also supports our finding that convenient access to water may not be a predictor of individual latrine use.

Regardless of the intensity and scale of the government-led sanitation intervention, which aims to reduce open defecation rates in rural India, people persist with the practice. This preference for open defecation, even among those with access to a latrine, has been revealed in this study and also resonates with findings from other studies (Planning Commission, 2013, Coffey et al., 2014). It has been suggested that this challenge may be addressed through intensive and targeted behavior change campaigns, which may be slow initially but once “adopted by a critical mass of people…become self-sustaining” (Sinha, 4 July 2016).

A number of limitations should be considered in the interpretation of these results. First, the observational nature of the study limits our ability to draw causal inferences, although we have attempted to account for temporality between predictor and outcome variables to gain better insight into likely associations, if any. Second, the population of households from which the sample was drawn was not representative of all households that received the intervention in a village as only those with a child under four years and/or a pregnant woman at baseline were included in the sampling frame. Third, reported use in the previous 48 hours was considered the primary measure for latrine use in this study based on empirical evidence from comparisons with instrumented monitoring. However, there is the potential of reporting bias and resulting imprecision in the latrine use measure. Fourth, the classification criteria for the categories of latrine use based on prior 48 hour recall may not be adequate to characterize consistency of use or intra-personal use. We have, therefore, also derived a longitudinal measure of use based on all three seasons, in an attempt to address this issue. However, the model with the longitudinal measure cannot incorporate time-variant covariates. Fifth, the possibility that the observed relationship between individual latrine use and the predictors of use may be due to the omission of certain unidentified variables might still be a concern in the interpretation of our results. However, an attempt has been made to include a reasonably comprehensive set of predictor variables that are likely to be associated with the outcome - individual latrine use. Finally, the study does not attempt to examine the extent to which latrine use may be associated with certain health outcomes of interest, for example, diarrhea, stunting or intestinal nematode infection, which were addressed in the Sanitation Trial. No attempt was made in this regard as evidence from the Sanitation Trial indicated that the intervention had no effect on the health outcomes of interest (Clasen et al., 2014).

8.6 Conclusions

To conclude, our study considers the methodological benefit in assessing longitudinal or consistent latrine use relative to use at a given time. It also suggests that the construction of subsidized latrines by the government in rural Odisha is insufficient to adequately address the “human development emergency” (Coffey et al., 2014) resulting from open defecation. Government policies and implementation practices that emphasize a strategic shift from building latrines to effectively triggering behavior change in the population may increase the demand for latrine use (MoDWS, 22 August 2014). This may be achieved through targeted interventions focused on an understanding of individual and household-level factors that presumably drive use of sanitation facilities.

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8.9 Disclosures

The authors have declared that no competing interests exist.

Table 8-1: Baseline characteristics of the study households and latrines

Variable	Sample unit	N (%)	Mean (SD)
Total households/ 25 villages	Households	310	
Total persons	Persons	2204	
Persons ≤ 3 years for duration of study	Persons	266	
Persons > 3 years included in study	Persons	1938	
Age	Persons	1938	32.24 years (19.41)
Gender	Persons		
Male		962 (49.64)	
Female		976 (50.36)	
Household size	Households		6.06 (2.90)
Head of household completed primary school	Households		
No		136 (43.87)	
Yes		174 (56.13)	
Mother/Carer of child completed primary school	Households		
No		76 (24.52)	
Yes		234 (75.48)	
Scheduled caste/tribe	Households		
No		251 (80.97)	
Yes		59 (19.03)	
Number of latrines per household	Households		
One latrine		268 (86.45)	
Two latrines		35 (11.29)	
Three latrines		7 (2.26)	
Latrine wall height of at least four feet or more	Households		
No		37 (11.94)	
Yes		273 (88.06)	
Presence of latrine door/ closure over entry	Households		
No		38 (12.26)	
Yes		272 (87.74)	
Presence of latrine roof	Households		
No		149 (48.06)	
Yes		161 (51.94)	
Own at least one minimally functional latrine*	Households		
No		23 (7.42)	
Yes		287 (92.58)	
Latrine distance measures	Households		
Distance from latrine to water, mean (SD)			18.68 (21.99)
Distance from latrine to house, mean (SD)			12.96 (15.21)
* Minimally functional latrine: Latrine with pan that is not broken/ choked/ blocked, pit (shared or independent), pit covered, pan-pit connection that is functional.			

Table 8-2: Model showing the effect of individual and household-level predictors on individual latrine use based on prior 48 hours recall (in any given season or round)

Variable	**Always/Usually vs. Never**				**Sometimes vs. Never**				**Always/Usually vs. Sometimes**		
	Multinomial Odds Ratio	**95% CI**	**p-value**		**Multinomial Odds Ratio**	**95% CI**	**p-value**		**Multinomial Odds Ratio**	**95% CI**	**p-value**
Female	2.24	1.87, 2.68	<0.001		1.99	1.48, 2.70	<0.001		1.12	0.82, 1.53	0.470
Age											
Age 4-12 years	0.90	0.71, 1.14	0.365		1.58	1.10, 2.27	0.014		0.57	0.41, 0.78	<0.001
Age 13-20 years	0.71	0.51, 1.01	0.056		0.84	0.45, 1.57	0.583		0.85	0.47, 1.54	0.597
Age 21-40 years	Ref.				Ref.				Ref.		
Age 41-59 years	0.68	0.53, 0.89	0.004		1.04	0.72, 1.52	0.828		0.66	0.44, 0.97	0.036
Age 60+ years	0.56	0.43, 0.73	<0.001		0.53	0.30, 0.93	0.028		1.05	0.62, 1.78	0.860
Scheduled caste/ tribe	0.55	0.25, 1.22	0.143		0.58	0.39, 0.88	0.010		0.94	0.48, 1.86	0.864
Head of household completed primary school	1.34	0.89, 2.03	0.164		1.21	0.88, 1.68	0.245		1.11	0.76, 1.61	0.598
Primary care giver completed primary school	1.29	0.96, 1.73	0.095		1.01	0.63, 1.63	0.965		1.27	0.85, 1.91	0.248
SES											
Wealth quintile 1	Ref.				Ref.				Ref.		
Wealth quintile 2	1.06	0.60, 1.91	0.821		1.32	0.65, 2.65	0.440		0.81	0.43, 1.52	0.513
Wealth quintile 3	1.11	0.72, 1.70	0.650		1.13	0.52, 2.48	0.755		0.98	0.51, 1.86	0.940
Wealth quintile 4	1.30	0.77, 2.19	0.326		1.04	0.59, 1.84	0.881		1.24	0.70, 2.21	0.457
Wealth quintile 5	1.49	0.69, 3.19	0.309		0.92	0.45, 1.88	0.822		1.61	0.85, 3.05	0.141
Household size	0.92	0.87, 0.97	0.003		0.87	0.83, 0.91	<0.001		1.05	0.99, 1.11	0.069

Distance between latrine-latrine water source	0.99	0.99, 1.00	0.312		0.99	0.99, 1.01	0.741		0.99	0.99, 1.00	0.493
Distance between latrine-house	0.99	0.99, 1.01	0.860		0.99	0.98, 1.01	0.324		1.00	0.99, 1.02	0.578
Latrine wall ≥ 4ft	1.10	0.66, 1.84	0.703		0.88	0.45, 1.72	0.712		1.25	0.70, 2.26	0.453
Latrine door	3.08	1.80, 5.28	<0.001		2.92	1.30, 6.58	0.010		1.05	0.51, 2.16	0.884
Latrine roof	2.00	1.30, 3.09	0.002		2.92	1.77, 4.83	<0.001		0.68	0.43, 1.09	0.108
Latrine functionality											
No minimally functional latrine	0.28	0.13, 0.61	0.001		0.27	0.08, 0.92	0.037		1.04	0.46, 2.35	0.929
One minimally functional latrine	Ref.				Ref.				Ref.		
Two minimally functional latrines	2.35	1.34, 4.13	0.003		2.10	1.03, 4.28	0.041		1.12	0.67, 1.88	0.673
Season											
Dry hot	Ref.				Ref.				Ref.		
Dry cold	1.50	1.18, 1.89	0.001		1.00	0.67, 1.49	0.995		1.5	0.97, 2.31	0.071
Rainy	1.34	1.07, 1.69	0.012		1.26	0.88, 1.82	0.213		1.06	0.77, 1.46	0.704

Table 8-3: Model showing the effect of individual and household-level predictors on consistent individual latrine use (across all three seasons or rounds)

Variable	Always/Usually vs. Never				Sometimes vs. Never				Always/Usually vs. Sometimes		
	Multinomial Odds Ratio	**95% CI**	**p-value**		**Multinomial Odds Ratio**	**95% CI**	**p-value**		**Multinomial Odds Ratio**	**95% CI**	**p-value**
Female	3.53	2.55, 4.89	<0.001		1.83	1.53, 2.18	<0.001		1.93	1.48, 2.52	<0.001
Age											
Age 4-12 years	0.88	0.55, 1.40	0.592		1.48	0.93, 2.37	0.099		0.59	0.42, 0.84	0.004
Age 13-20 years	0.63	0.30, 1.31	0.216		0.75	0.38, 1.50	0.420		0.83	0.40, 1.74	0.630
Age 21-40 years	Ref.				Ref.				Ref.		
Age 41-59 years	0.45	0.30, 0.67	<0.001		0.68	0.43, 1.05	0.080		0.67	0.49, 0.91	0.011
Age 60+ years	0.34	0.19, 0.58	<0.001		0.57	0.32, 1.01	0.054		0.59	0.40, 0.88	0.009
Scheduled caste/ tribe	0.43	0.15, 1.24	0.117		0.42	0.24, 0.75	0.003		1.01	0.48, 2.17	0.971
Head of household completed primary school	1.10	0.54, 2.22	0.797		0.93	0.55, 1.59	0.796		1.18	0.75, 1.84	0.478
Primary care giver completed primary school	1.02	0.58, 1.76	0.957		0.83	0.42, 1.65	0.597		1.22	0.66, 2.28	0.529
SES											
Wealth quintile 1	Ref.				Ref.				Ref.		
Wealth quintile 2	1.00	0.32, 3.11	1.000		1.06	0.44, 2.56	0.900		0.95	0.51, 1.75	0.856
Wealth quintile 3	2.03	0.82, 5.04	0.125		2.73	1.20, 6.22	0.017		0.74	0.43, 1.28	0.289
Wealth quintile 4	1.38	0.59, 3.25	0.458		1.21	0.57, 2.54	0.618		1.14	0.56, 2.32	0.711
Wealth quintile 5	2.04	0.58, 7.17	0.266		1.15	0.37, 3.63	0.809		1.77	0.94, 3.35	0.079

Household size	0.92	0.86, 0.99	0.018		0.96	0.90, 1.03	0.256		0.96	0.89, 1.03	0.276
Distance between latrine-latrine water source	0.99	0.98, 1.01	0.497		1.00	0.99, 1.02	0.501		0.99	0.98, 1.00	0.029
Distance between latrine-house	0.99	0.97, 1.02	0.511		1.01	0.99, 1.02	0.196		0.98	0.96, 1.01	0.249
Latrine wall ≥ 4ft	1.03	0.40, 2.69	0.946		0.85	0.36, 2.01	0.708		1.22	0.54, 2.77	0.635
Latrine door	7.29	1.60, 33.22	0.010		3.13	1.02, 9.59	0.046		2.33	0.92, 5.91	0.075
Latrine roof	4.73	2.23, 10.04	<0.001		3.91	1.72, 8.90	0.001		1.21	0.89, 1.64	0.217
Latrine functionality											
No minimally functional latrine	0.34	0.08, 1.54	0.162		0.28	0.06, 1.40	0.121		1.22	0.27, 5.60	0.796
One minimally functional latrine	Ref.				Ref.				Ref.		
Two minimally functional latrines	2.35	0.90, 6.12	0.081		1.27	0.38, 4.26	0.699		1.85	1.07, 3.17	0.025

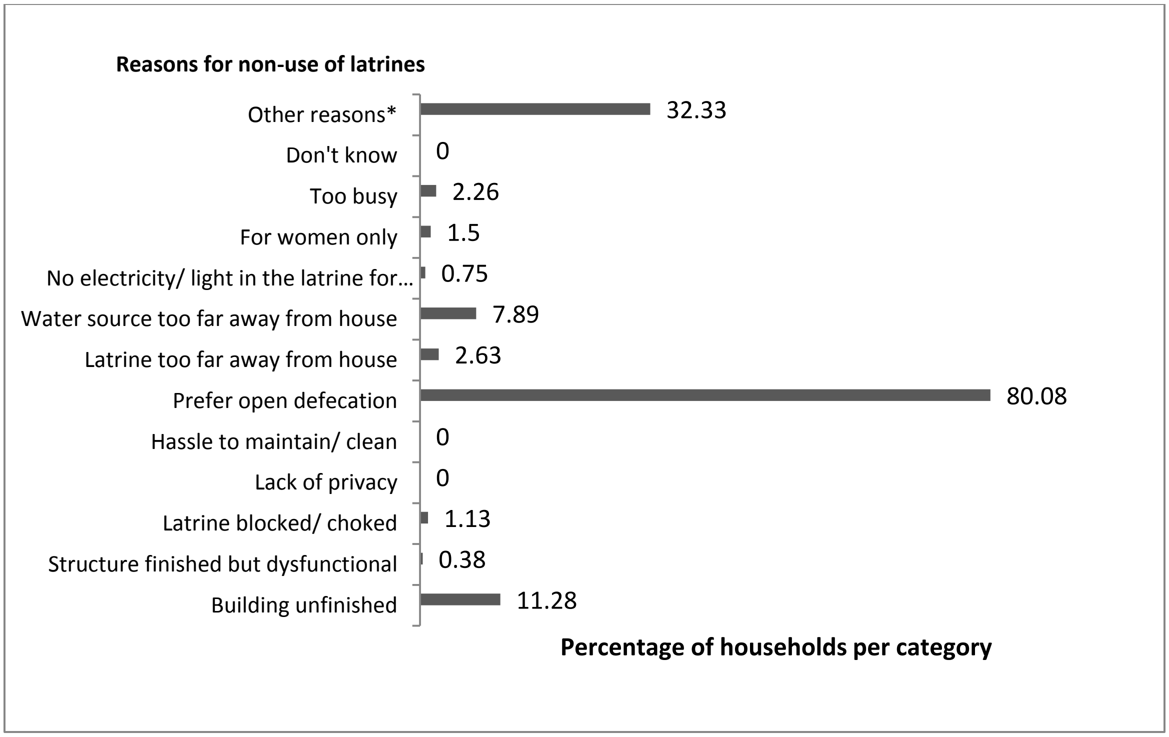

Figure 8-1: Reported reasons for non-use of latrines among latrine owning households in sample (N=266).

8.10 References: Chapter 8

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9 Summary, reflections and way forward

9.1 Summary

The overall aim of this research was to improve the effectiveness of sanitation efforts in low income countries by advancing the methods for assessing latrine use in these settings and by furthering our understanding of the patterns and determinants of latrine use in a rural context. Previous research has shown that existing methods that rely on latrine access and coverage in order to monitor sanitation progress are often inadequate measures of programme outcomes and impact (WSP, 2013, Planning Commission, 2013, Coffey et al., 2014). Regardless, both international and national sanitation monitoring efforts seem to continue to emphasise these output indicators, while neglecting to monitor latrine use, an important outcome indicator (WHO-UNICEF, October 2015). A partial explanation for this may be the uncertainty about the reliability of existing methods to assess latrine use (Curtis et al., 1993, Manun'Ebo et al., 1997, Zwane et al., 2011, Clasen et al., 2012b, Patil et al., 2014, Bartram et al., 2014, Arnold et al., 2015). This research was designed to address the methodological issues associated with latrine use assessment measures with a view to recommending an improvement in current methods. It was also designed to provide evidence on the patterns and determinants of use to inform programmatic interventions.

The study was conducted in a rural, coastal district in India, among villages that comprised part of the intervention arm of a randomised controlled trial (the "Sanitation Trial") to assess the health impact of rural sanitation under the Indian TSC (Clasen et al., 2012a, Clasen et al., 2014). The intervention included the construction of pour-flush latrines among eligible "below the poverty line" households and community mobilisation activities. Households that were included in the Sanitation Trial surveillance (had a child under 4 years and/or a pregnant woman at baseline) and had a functional latrine as a result of the intervention were eligible to participate in the study. Latrine use, with specific reference to defecation events, was assessed through four household and individual-level measures. The agreement at a given point in time was assessed primarily between comparative categories of PLUM-based measures of use and survey-based reported use. Latrine use was measured once in each season, the dry cold, dry hot and rainy seasons, over 12 months, to address potential seasonal variations in use, consistency of latrine use, and the determinants of use. Below is a summary of key findings.

9.1.1 Cross-sectional study comparing reported use and Passive Latrine Use Monitors

- The results comparing reported latrine use and PLUM-recorded latrine events revealed that, on average, the reported use measures were consistently higher than the corresponding PLUM-recorded latrine events across the range of comparisons. The mean reported "usual" daily events per household (7.09, 95% CI = 6.51, 7.68) was nearly twice that of the PLUM-recorded daily average (3.62, 95% CI = 3.29, 3.94).
- Reported use on days 13 and 14 were also higher than their corresponding PLUM-recorded latrine events, but that difference was markedly less. The average PLUM-recorded latrine events were similar for the 14 day observation period (3.62, 95% CI = 3.29, 3.94) and for the prior 48 hours (3.59, 95% CI = 3.23, 3.94). It was therefore considered reasonable to compare the PLUM-recorded daily average for the 14 day observation period with average reported use for the prior 48 hours as the fourth comparison category.
- There was poor agreement between "usual" daily latrine use and the average daily PLUM-recorded events (ρ_c = 0.331, 95% CI = 0.242, 0.427). Moderate agreement (ρ_c = 0.598, 95% CI = 0.497, 0.683) was obtained when comparing daily reported use during the previous 48 hours with the average daily PLUM count over 14 observation days.
- Reported latrine use, though already suggesting low adoption, likely exaggerates the actual level of uptake of latrines constructed under the program. Where reliance on

self-reports is used, survey questions should focus on the 48 hours prior to the date of the survey rather than asking about “usual” latrine use behaviour.

9.1.2 Longitudinal study to assess patterns and determinants of latrine use

- In the study population, individual reported use based on a prior 48 hour recall measure, was classified into “always/usually”, “sometimes” and “never” use. Results suggested low levels of latrine use in the study population. In any given season or round, of the members of latrine-owning study households, an average of 43.5% (95% CI = 37.9, 49.1) individuals reported never using the latrine, an average of 4.6% (95% CI = 3.8, 5.5) individuals reported sometimes using the latrine, and an average of 51.9% (95% CI = 46.2, 57.5) reported always/usually using the latrine.
- Only two-thirds of those who reported always/usually using a latrine in round one reported the same for all three rounds.
- Of the members of latrine-owning study households, 30.1% (95% CI = 23.0, 37.2) of individuals reported never using the latrine, 33.2% (95% CI = 28.3, 38.1) reported sometimes using the latrine, and 36.8% (95% CI = 31.8, 41.8) reported always/usually using the latrine across all three seasons. This finding suggested a decrease in the average response probability of individuals who report always using the latrine from 51.9%, when assessed in any given season, to 36.8%, when assessed longitudinally. This finding underscores the challenge in ensuring latrine use, which is also consistent and sustained.
- The results suggested a seasonal variation in reported individual latrine use behaviour based on 48 hour recall. The reported likelihood of always/usually versus never using the latrine was significantly greater in the dry cold season relative to the dry hot season (OR = 1.50, 95% CI = 1.18, 1.89, p = 0.001). The predicted probability of always/usual latrine use showed an absolute increase of 8.2% (95% CI = 3.4, 13.0, p = 0.001) in the dry cold versus dry hot season. Conversely, we observed an

absolute reduction of 7.1% (95% CI = 2.8, 12.6, p = 0.001) in the probability of never using a latrine during the dry cold season compared to the dry hot season.

- The evidence also indicated that reported likelihood of always/usually versus never using the latrine was significantly greater in the rainy season than in the dry hot season (OR = 1.34, 95% CI = 1.07, 1.69, p = 0.012). We observed an absolute increase of 5.6% (95% CI = 1.0, 9.7, p = 0.016) in the predicted probability of always/usual latrine use in the rainy season compared to the dry hot season. The probability of never use during the rainy season was decreased by 5.4% (95% CI = 1.2, 10.1, p = 0.014) compared to the dry hot season. There were no observed seasonal differences in the probability of sometimes use.
- Among the a priori selected predictors of latrine use, females were significantly more likely than males to report always/usually using the latrine versus never using it, both when assessed in any given season and longitudinally (for consistent latrine use). They were also significantly more likely than males to report sometimes versus never using the latrine than males, both in the analysis in any given season and in the longitudinal analysis. Further, females were also significantly more likely to than males to report always/usually versus sometimes using the latrine in the longitudinal assessment.
- The evidence suggested a decreased likelihood of age groups 41-59 years and 60+ years reporting always/usually using the latrine versus never using it when assessed both in any given season and for consistent latrine use.
- The results from analyses in any given season and for consistent use also suggested that as household size increases, there is a decreased likelihood in individuals reporting always/ usual use of the latrine versus never using it.
- Analyses, both in any given season and longitudinally, suggested that the presence of a latrine door or closure for privacy and a latrine roof significantly increased the likelihood of individuals reporting always/usually versus never using the latrine and sometimes versus never using it.

- Among the cited reasons for non-use of household latrines, respondents from 80.1% study households (N=266) suggested that they preferred open defecation.

9.1.3 Implications

The following implications may be drawn from the findings mentioned above.

- Reported latrine use, though already suggesting low adoption, likely exaggerates the actual level of uptake of latrines constructed under the TSC. However, where reliance on self-reports is used, survey questions should focus on the 48 hours prior to the date of the survey rather than asking about “usual” latrine use behaviour.
- There may be a methodological benefit to assessing consistency of latrine use over time relative to use at a given time as it is likely to better characterise intra-personal use.
- The findings regarding seasonal variation in reported latrine use suggest lower use in the dry hot months relative to the dry cold and rainy seasons. It implies that it may be beneficial to intensify ground-level campaign efforts in the dry hot season to re-inforce sanitation messages and drive greater use.
- Intensive and targeted behaviour change campaigns aimed at ensuring that all those with access to latrines actually use them may consider prioritising various determinants of consistent use based on available evidence. Therefore, targeting females in households, for example, and considering them as change agents may prove to be beneficial. Further, ensuring that all latrines that are constructed as a result of the government’s sanitation programme meet necessary structural specifications, such as presence of a latrine door and roof, is likely to drive consistent use. Equally, it may be useful to review the number of latrines offered to households based on household size, where larger households are eligible for additional latrine facilities. Additionally, it may be strategic to customise behaviour change campaigns to various age-groups given likely variations in mind-set and habitual preferences.

9.2 Reflections

The study incorporated elements in design and methods intended to address shortcomings of most previous research on latrine use assessment. Chief among these was the use of various methods, including a potentially objective sensor-based method, to simultaneously monitor latrine use in the study population and to enable validation of an approach that may be used programmatically. These were both household and individual level measures of latrine use, thereby also offering potentially useful data on consistent users and refractory members in study households. Follow-up was for an entire year, compared to most previous studies that have followed a cross-sectional design. In addition to methodological outcomes based on comparison of latrine use measures, the results included seasonal monitoring of various predictors of use to estimate the determinants of longitudinal or consistent latrine use, an aspect that differs from previous research on the subject.

Looking back on the study, however, there are aspects of the design and methods that could have been improved. These may be considered in addition to the limitations already included in Chapters 7 and 8.

9.2.1 Cross-sectional study comparing reported use and Passive Latrine Use Monitors

- The SweetSense PLUMs used in this study were more advanced than the previous versions that were tested (Chapter 5). However, there were certain design and systemic features that could be improved further in order to make the units resistant to extreme and harsh weather conditions, such as heat and humidity. The units could also be made more secure and tamper-proof.
- The latrine event algorithm that estimates likely defecation events requires further testing and validation. Although pilot studies were conducted to validate the algorithm in the context of this study, more extensive work is required in this area. For example, it may be beneficial to pursue the validation of the algorithm in a small-scale pilot through simultaneous PLUM-based recordings, latrine use

simulations and the use of the door switch. This testing may then be scaled up in the next phase, excluding latrine use simulations. Our study timelines did not permit such extensive testing.

- The installation procedure for the PLUM needs to be refined (and standardised to the extent possible) to enable secure installation of the unit with minimal damage to the latrine. Further, installation procedures should also account for variations in latrine super-structures, for example, PLUM installation in latrines that do not have an enclosure or have enclosures made with sack cloth or have no roof.
- The quality-control procedures with reference to the PLUM could have been more extensive. The remote location of the study sites made continuous close monitoring challenging. The existing procedure did not permit any remote real-time monitoring, as envisaged, as the cellular coverage in the study villages was poor. The data was stored in a back-up SD card in the unit instead of getting uploaded on the MySQL server in real time using the cellular network. We did not want to increase the number of visits beyond two per household per round in the likelihood that it may increase potential behavioural reactivity or reporting bias.
- This research did not include a sub-study to assess potential behavioural reactivity to the sensors. Evidence from a recent study suggests that it may be present (Thomas et al., 2016) and it would be beneficial to account for likely bias or reactivity to awareness of electronic sensors in the analysis.
- The study did not account for potential bias resulting from the extensive, albeit unavoidable, pilot testing with the 3G PLUM in the study population in 2011-2012. Additionally, the awareness among the surveillance households of participating in the Sanitation Trial may have influenced their latrine use behaviour and reporting of sanitation practices.

9.2.2 Longitudinal study to assess patterns and determinants of latrine use

- The study did not examine the extent to which latrine use may be associated with health outcomes of interest that were addressed in the Sanitation Trial as the evidence from the trial indicated that the intervention had no effect on the health outcomes of interest (Clasen et al., 2014). This may be explored in the future. Ideally all latrine owning households in the randomly selected intervention villages, not just surveillance households, would be included in the sample to arrive at a community-wide estimate of latrine use. Existing funding was inadequate to meet the associated cost and logistics of such a large study.

- The study did not adequately address the issue of child faeces disposal. The latrine spot-check measure included an indicator on the presence of (human) faeces in the household compound. However, this indicator was not reliable for several reasons. For example, in the rainy season, the grounds surrounding households were often flooded or had tall grass making it challenging to observe. Also, households were often clustered and compounds were seldom clearly demarcated making it difficult to ascertain which household was responsible for the observed faeces in the surrounding area.
- The survey-based reported use measure did not include any questions on child faeces disposal, including in the latrine. Future studies should also consider querying individuals on reported use of latrines for disposal of child faeces as it is an important aspect of sanitation programmes.
- In our study, we drew from previous research (Manas Kumar et al., 2013) and a pilot study to classify latrine users into categories of "always/usually", "sometimes" and "never" use based on prior 48 hour recall. However, we recognised that a prior 48 hour recall measure in any given season or round may not be a reliable measure of intra-personal latrine use and may result in mis-classification error. We constructed a longitudinal measure of individual latrine use that estimated use based on all three seasons in order to reduce potential mis-classification error. Nevertheless, we cannot say with certainty that this has been minimised. It warrants further verification.
- Baseline findings indicated that only approximately 10% of the study households had access to a latrine prior to the intervention. Since the study population comprised

relatively new latrine owners, we were unable to explore potential associations between length of time of latrine ownership and use, as has been examined elsewhere (O'Reilly and Louis, 2014).

- The study findings may be relevant to a sanitation programme in its early stages since the programme in the context of this study was relatively new.

9.3 Way forward

Government and other sanitation programmes that aim to end open defecation in rural areas through educational campaigns and the construction of subsidised household latrines are unlikely to have an impact on the environment and health unless the facilities are used consistently by the target population (WSP, 2011a, Planning Commission, 2013, Coffey et al., 2014). Our study has shown that a large and intense campaign along these lines was not sufficient to ensure high uptake and consistent use among the target population. These findings are not isolated. They are aligned with results from other studies that despite efforts to provide latrine access and increase coverage, open defecation rates have not meaningfully reduced (Garn et al., 2016). Furthermore, these findings have programme implementation and policy implications that merit further research when framed within the "2030 Sustainable Development Agenda" (SDA2030) and the Sustainable Development Goal Target 6.2 (WHO-UNICEF, October 2015). It states:

> "By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women, girls and those in vulnerable situations."

Closer analysis of currently available underlying normative definitions and indicators reveals that there may be no further clarity on latrine use monitoring beyond the guidance available in the MDG period (WHO-UNICEF, October 2015). Although other "high use" and "high risk" settings, such as schools, workplaces, healthcare facilities, etc.

have been included, there appears to be continued emphasis on individual household facilities and the use of the facility by all household members.

Reflecting on the way forward in this context, the following may be considered:

- Further research to develop relatively objective, robust and preferably inexpensive methods to assess individual use of latrines that may be integrated into large-scale monitoring efforts. Individual use measures that also capture sex, age and disability data may be useful in profiling members and pointing to intra-household inequalities. Reliable measures of consistent use will also need to be explored to enable progress monitoring temporally.
- Use of sensor-based technologies to monitor latrine use offers a promising approach. When used concurrently with other measures, it also may be used to validate those measures (O'Reilly et al., 2015). This research adds to a growing body of evidence on methods to assess latrine use, including sensor-based methods, both in country and outside. The study led by Clasen and colleagues in Bangladesh, 2014 (Delea and Clasen) is one such example. It may be useful to conduct a pooled analysis of datasets from these studies reporting on latrine use in varying contexts in an effort to develop a tool that allows for more rigorous monitoring of outcomes.
- Household measures, although not analysed adequately in this research, remain popular measures of latrine use. The data on latrine spot-checks and latrine construction and functionality indicators available through this study may be used to assess the reliability and validity of those measures, especially when compared with the PLUM.
- Many existing sanitation campaigns include infrastructure development and information, education and communication efforts. However, there is a need to better understand the key motivators or drivers with regard to sanitation practices (O’Reilly and Louis, 2014, Coffey et al., 2014, Dreibelbis et al., 2015) and customise interventions to the target population.

- Sanitation programmes are unlikely to have an impact on health unless latrines are used consistently by all in the target population. The data on consistent latrine use available through this study may be used in a secondary analysis to explore associations between latrine use and health.

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APPENDIX

HH ID: __ __ __ __ __ __

APPENDIX 1

MODULE A: IDENTIFICATION INFORMATION		
A1	Village code [REFER TO LIST]	☐☐☐
A2	Household ID [REFER TO LIST]	☐☐☐☐☐☐
A3	Enumerator code	☐☐
A4	Name of head of household [MATCH WITH NAME IN LIST TO CONFIRM] ଘରର ମୁଖିଆଙ୍କ ନାମ	
A5	Gender of head of household (Male/ Female) ଘରର ମୁଖିଆଙ୍କ ଲିଙ୍ଗ	M / F
A6	Total number of members in household [MATCH WITH TOTAL NUMBER IN LIST TO CONFIRM] ଘରର ସଦସ୍ୟଙ୍କ ସଂଖ୍ୟା	☐☐
A7	Name of respondent ଉତରଦାତାଙ୍କ ନାମ	
A8	Position in household ଘରର ମୁଖିଆଙ୍କ ସହିତ ସମ୍ପର୍କ [IN RELATION TO THE HEAD OF HOUSEHOLD, E.G., WIFE, SON, DAUGHTER-IN-LAW ETC.]	
Remarks:		

MODULE B: LATRINE CONSTRUCTION AND FUNCTIONALITY STATUS				
Date (dd/mm/yyyy): __ __ / __ __ / __ __ __ __				
B1	Does your household have access to a latrine? ଆପଣଙ୍କ ଘରେ ପାଇଖାନାର ସୁବିଧା ଅଛି କି ?	Yes No	01 02	Continue End
B2	Does your household have a latrine? ଆପଣଙ୍କର ନିଜର ପାଇଖାନା ଅଛି କି ?	Yes No	01 02	 Skip to B4
B3	Do any members of your household ever use the latrine(s)? ଆପଣଙ୍କ ଘରର କେହିବି ସଦସ୍ୟ ପାଇଖାନା ବ୍ୟବହାର କରିଛନ୍ତି କି ?	Yes No	01 02	Skip to B5
B4	Do any members of your household usually use any others latrines in the village? ପ୍ରାୟତଃ ଆପଣଙ୍କ ପରିବାରର କୌଣସି ବ୍ୟକ୍ତି ଗାଁର ଅନ୍ୟ କୌଣସି ପାଇଖାନା ବ୍ୟବହାର କରନ୍ତି କି ?	Yes No	01 02	Notes→End End

	Enumerator, check: a. If B4 → 01, note name of the head of latrine owning household: b. Check if it is a surveillance household: Y / N [MATCH WITH LIST/ VISIT AND CIRCLE ACCORDINGLY] c. If yes (Y), note household ID [REFER TO LIST]: d. Note total number of members of household who use <u>other</u> latrine:		
B5	How many latrines do you have? [CAN YOU PLEASE SHOW ME THE LATRINE(S)?] ଆପଣଙ୍କର ନିଜର କେତୋଟି ପାଇଖାନା ଅଛି ?	One Two Three More than three	01 02 03 04
	Observe or ask and record What type of latrine facility does your household have? [ASK IF NOT OBSERVABLE] ଆପଣଙ୍କ ପାଇଖାନାଟି କେଉଁ ପ୍ରକାରର ?		
B6A	Latrine 1	Flush or pour flush latrine to: pit tank elsewhere Pit latrine with slab Open pit latrine Other (specify)	 01 02 03 04 05 88
B6B	Latrine 2	Flush or pour flush latrine to: pit tank elsewhere Pit latrine with slab Open pit latrine Other (specify)	 01 02 03 04 05 88
B6C	Latrine 3	Flush or pour flush latrine to: pit tank elsewhere Pit latrine with slab Open pit latrine Other (specify)	 01 02 03 04 05 88
	How long ago was/were your latrine(s) built? ଆପଣଙ୍କ ପାଇଖାନା କେବେ ତିଆରି ହୋଇଥିଲା ? [PROMPTED RESPONSE]		
B7A	Latrine 1	Months Can't remember/ Don't know	_ _ 99
B7B	Latrine 2	Months Can't remember/ Don't know	_ _ 99
B7C	Latrine 3	Months Can't remember/ Don't know	_ _ 99
	Enumerator, check: a. If more than one latrine (excluding 03/05), use separate sheets from B8 to B25 in this module.		

B8	**Latrine number** [RECORD IN DIGITS]	__ __		
B9	Did you receive any cash, materials or labour from an NGO to build the latrine? ପାଇଖାନା ତିଆରି ବାବଦରେ ଆପଣ ବେସରକାରୀ ସଂସ୍ଥାପାଖରୁ କୌଣସି ପ୍ରକାରର ଅର୍ଥ, ଜିନିଷ ବା ମୁଲିଆ ପାଇଥିଲେ କି ?	Yes No Don't know	01 02 99	
B10	*Observe and record* Height of latrine enclosure [USE MEASURING TAPE TO MEASURE HEIGHT FROM SLAB UPWARD] ପାଇଖାନା କାନ୍ଥର ଉଚ୍ଚତା ମାପନ୍ତୁ	No enclosure Enclosure less than 4 feet 4 foot enclosure Full height of enclosure(i.e, person's head not visible while squatting) Others (specify)	01 02 03 04 88	Skip to B12
B11	*Observe and record* Material of latrine enclosure ପାଇଖାନାର ଘେରା କେଉଁଥିରେ ତିଆରି ?	Cloth/ Plastic/ Sack Bamboo/ Coconut mat Stone Un-plastered bricks Plastered bricks Plastered bricks with tiles Others (specify)	01 02 03 04 05 06 88	
B12	*Observe and record* Presence of latrine closure/door over entry for privacy? ପାଇଖାନାକୁ ବନ୍ଦ କରିବା ପାଇଁ ସୁବିଧା ଅଛି କି ?	Yes No	01 02	 Skip to B14
B13	*Observe and record* Type of latrine closure/door ପାଇଖାନାର କବାଟ କେଉଁ ପ୍ରକାରର ?	Wood Curtain/ Cloth Plastic sheet Metal sheet Others (specify)	01 02 03 04 88	
B14	*Observe and record* Presence of latrine roof ପାଇଖାନାର ଛାତ ଅଛି କି ?	Yes No	01 02	 Skip to B16
B15	*Observe and record* Type of latrine roof ପାଇଖାନାର ଛାତ କେଉଁ ପ୍ରକାରର ?	Thatched/ Grass/ Plastic Corrugated tin/ Asbestos Tiles Concrete Others (specify)	01 02 03 04 88	
B16	*Observe and record* Floor material around pan ଚଟାଣଟି କେଉଁଥରେ ତିଆରି ?	Concrete only Concrete and tiled Others (specify)	01 02 88	

B17	*Observe and record* Pan condition ପ୍ୟାନର ଅବସ୍ଥା କଣ ?	Broken Not broken Choked Others (specify)	01 02 03 88	
B18	*Observe or ask and record* Number of pits per latrine ପ୍ରତି ପାଇଖାନାର କେତୋଟି ଗର୍ତ୍ତ	None One Two Don't know Others (specify)	01 02 03 99 88	Skip to C1
	Enumerator, check: a. If only 1 pit, record for B19 – B22 b. For pit 2, if relevant, record for B23 – B26			
	Pit one			
B19	*Observe or ask and record* Pit ଗର୍ତ୍ତ [ASK IF PIT NOT OBSERVABLE]	Pit with less than 3 rings Pit with 3 rings or more Don't know Others (specify)	01 02 99 88	
B20	*Observe and record* Pit covering ଗର୍ତ୍ତର ଘୋଡଣି	Pit open or part open Pit visible and fully covered Pit buried or not visible Others (specify)	01 02 03 88	 Skip to B22 Skip to B22
B21	*Ask and record* If the pit is uncovered, why is it uncovered? ଯଦି ଗର୍ତ୍ତଟି ଖୋଲା ଅଛି ତେବେ କାହିଁକି ?	No cover supplied Cover broken Cover is missing NGO mason did not complete work Don't know Others (specify)	01 02 03 04 99 88	
B22	*Observe or ask and record* Pan-pit pipe connection ପ୍ୟାନ ସହିତ ପିଟ୍ ପାଇପ୍ର ଯୋଡେଇ [ASK IF CONNECTION NOT OBSERVABLE]	Pan-pit not connected Pan-pit connected and functional Pit latrine with slab – no connection Can't tell/ Don't know Others (specify)	01 02 03 99 88	

	Pit two [IF NO SECOND PIT, SKIP TO C 1]			
B23	*Observe or ask and record* Pit ଗର୍ତ୍ତ [ASK IF PIT NOT OBSERVABLE]	Pit with less than 3 rings Pit with 3 rings or more Don't know Others (specify)	01 02 99 88	
B24	*Observe and record* Pit covering ଗର୍ତ୍ତର ଘୋଡଣି	Pit open or part open Pit visible and fully covered Pit buried or not visible Others (specify)	01 02 03 88	 Skip to B26 Skip to B26
B25	*Ask and record* If the pit is uncovered, why is it uncovered? ଯଦି ଗର୍ତ୍ତଟି ଖୋଲା ଅଛି ତେବେ କାହିଁକି ?	No cover supplied Cover broken Cover is missing NGO mason did not complete work Don't know Others (specify)	01 02 03 04 99 88	
B26	*Observe or ask and record* Pan-pit pipe connection ପ୍ୟାନ ସହିତ ପିଟ୍ ପାଇପ୍‌ର ଯୋଡେଇ [ASK IF CONNECTION NOT OBSERVABLE]	Pan-pit not connected Pan-pit connected and functional Pit latrine with slab – no connection Can't tell/ Don't know Others (specify)	01 02 03 99 88	

Remarks:

HH ID: __ __ __ __ __ __

MODULE C: LATRINE SPOT-CHECK OBSERVATIONS			
Enumerator: Observe and record the indicators of latrine use that are applicable. If the household has more than one latrine, record the latrine number (same as B8) and identify applicable indicators of use (C1 – C13 only) for each latrine separately using additional sheets. Date (dd/mm/yyyy): __ __ /__ __ / __ __ __ __ Latrine number (as in B8): __ __ Start of observation: __ __ __ __(hh:mm) End of observation: __ __ __ __(hh:mm)			
C1	Is there evidence that this latrine is used for storage? ପାଇଖାନାରେ ଜିନିଷ ସଂରକ୍ଷିତ ରଖିବାର ପ୍ରମାଣ ଅଛି କି ?	Yes No	01 02
C2	Well-worn path to the latrine ପାଇଖାନାକୁ ଯିବା ପାଇଁ ଭଲ ରାସ୍ତା ଅଛି କି ?	Yes No	01 02
C3	Wet floor ଓଦା ଚଟାଣ	Yes No	01 02
C4	Odour of stool/urine ଝାଡା/ପରିସ୍ରା ଗନ୍ଧ	Yes No	01 02
C5	Flies in latrine ପାଇଖାନା ଭିତରେ ମାଛି	Yes No	01 02
C6	Dis-colouration of pan (e.g. yellow/ green) ପ୍ୟାନର ରଙ୍ଗ କମିଯିବା (ସବୁଜ ବା ହଳଦିଆ)	Yes No	01 02
C7	Presence or traces of faeces in pan ପ୍ୟାନ ଉପରେ ଝାଡା	Yes No	01 02
C8	Water container in/ near the latrine ପାଇଖାନାରେ ବା ପାଖରେ ପାଣି ପାତ୍ର	Yes No	01 02
C9	Cleaning agents inside the latrine (e.g broom, bleach etc.) ପାଇଖାନାକୁ ସଫା କରିବା ପାଇଁ ଉପକରଣ (ଝାଡୁ, ବ୍ରସ)	Yes No	01 02
C10	Slippers outside or inside the latrine ପାଇଖାନା ଭିତରେ ବା ବାହାରେ ଚପଲ	Yes No	01 02
C11	Leaves/dirt/spider webs in the pan ପ୍ୟାନ୍‌ରେ ପତ୍ର,ମଇଳା,ବୁଢିଆଣି ଜାଲ ଅଛି କି ?	Yes No	01 02
C12	Water for hand-washing inside or near the latrine ପାଇଖାନା ଭିତରେ ବା ପାଖରେ ହାତ ଧୋଇବା ପାଇଁ ପାଣି ଅଛି କି ?	Yes No	01 02
C13	Soap/ash for hand-washing inside or near the latrine ହାତ ଧୋଇବା ପାଇଁ ସାବୁନ, ଅଙ୍ଗାର ବା ଅନ୍ୟ କିଛି ଅଛି କି ?	Yes No	01 02

	Observation of human stools outside latrine. Walk around the compound of the house for 5 minutes. ପାଇଖାନା ଆଖପାଖରେ ମଣିଷର ମଳ ଅଛି କି ଦେଖନ୍ତୁ । ଘରର ପରିଶରରେ କିଛି ସମୟ ବୁଲନ୍ତୁ ।		
C14	Observe and record the presence of human stools in the compound ମଣିଷର ମଳ ଗୃହ ପରିଶରରେ ଅଛି କି ଦେଖନ୍ତୁ ଓ ଲେଖନ୍ତୁ	Yes No	01 02

Remarks:

MODULE D: REPORTED LATRINE USE

Enumerator: Identify an adult female (in the following order of preference: 1. mother-in-law 2. eldest daughter-in-law 3. daughter 4. middle daughter-in-law) in the household for responses. In D2, D4, D5, if family member present and self-reports, please note the same. ଉତର ଦାତା ଭାବରେ ଘରର ବୟସ୍କ ମହିଳାଙ୍କୁ ଚିହ୍ନଟ କରନ୍ତୁ- (ଯେପରିକି,୧.ଶାଶୁ, ୨.ବଡ ବୋହୂ, ୩.ଝିଅ, ୪.ମଝିଆଁ ବୋହୂ).ଯଦି ପରିବାରର ସଦସ୍ୟମାନେ ଉପସ୍ଥିତ ଅଛନ୍ତି ତେବେ ତାଙ୍କଠାରୁ ଉତର ସଂଗ୍ରହ କରନ୍ତୁ ।

Name of respondent:
ଉତର ଦାତାଙ୍କ ନାମ

Position in family [in relation to the head of household, e.g wife]:
ଘରର ମୁଖିଆଙ୍କ ସହିତ ସମ୍ପର୍କ

Age: __ __ yr

Date (dd/mm/yyyy): __ __ /__ __ / __ __ __ __

Start time: __ __ __ __(hh:mm) End time: __ __ __ __(hh:mm)

D1 For each member in your household, please tell us the name, age, gender and ***usual*** place of defecation (through the year) starting ***with the eldest.***

Sl.No	Name	Age	Gender 01 = M 02 = F		Usual place of defecation 01 = Latrine always 02 = Latrine usually 03 = Latrine sometimes 04 = Open defecation always 05 = Defecation within household compound always 88 = Other (specify)						01 = Report 02 = Self-report	
1			01	02	01	02	03	04	05	88	01	02
2			01	02	01	02	03	04	05	88	01	02
3			01	02	01	02	03	04	05	88	01	02
4			01	02	01	02	03	04	05	88	01	02
5			01	02	01	02	03	04	05	88	01	02
6			01	02	01	02	03	04	05	88	01	02
7			01	02	01	02	03	04	05	88	01	02
8			01	02	01	02	03	04	05	88	01	02
9			01	02	01	02	03	04	05	88	01	02
10			01	02	01	02	03	04	05	88	01	02

Remarks:

	Enumerator, check: Use supplementary sheet, if required, to record details of remaining household members. Supplementary sheet used (YES/ NO): Y / N ଆବଶ୍ୟକ ହେଲେ ଅନ୍ୟ ଏକ ଫର୍ମ ବ୍ୟବହାର କରନ୍ତୁ ।		[Skip to D3 if all= 01 and 02]
D2	Is the latrine used more than usual at any time in the year? ପାଇଖାନାଟି ବର୍ଷର କେଉଁ ସମୟରେ ଅଧିକ ବ୍ୟବହାର କରାଯାଏ ?	Rains Summer Winter Same year round Don't know	01 02 03 04 99
D3	Is the latrine used less than usual at any time in the year? ପାଇଖାନାଟି ବର୍ଷର କେଉଁ ସମୟରେ କମ୍ ବ୍ୟବହାର କରାଯାଏ ?	Rains Summer Winter Same year round Don't know	01 02 03 04 99

D4	Of those who do not always use the latrine, what are their reasons for not using it? [CHECK ALL THAT APPLY. DO NOT PROMPT] ଯେଉଁମାନେ ଅଧିକାଂଶ ସମୟ ପାଇଖାନା ବ୍ୟବହାର କରନ୍ତିନାହିଁ, ତାର କାରଣ କଣ ?	Reasons	Y	N
		Building unfinished	01	02
		Structure finished but dysfunctional	01	02
		Blocked	01	02
		Lack of privacy	01	02
		Hassle to maintain/ clean	01	02
		Prefer open defecation	01	02
		Latrine too far away from house	01	02
		Water source too far away from house	01	02
		No light/electricity in the latrine for use at night	01	02
		For women only	01	02
		Too busy	01	02
		Don't know	99	
		Other (specify)	88	

D5	Among your family members who use the latrine, can you tell me how many times in the day they usually use the latrine? ଆପଣଙ୍କ ପରିବାରର ଯେଉଁମାନେ ପାଇଖାନା ବ୍ୟବହାର କରନ୍ତି,ସେମାନେ ଦିନକୁ କେତେ ଥର ବ୍ୟବହାର କରନ୍ତି ଦୟାକରି କହବେକି ? [REFER TO LIST FROM D2 AND MATCH THE SERIAL NUMBER/ NAME OF HH MEMBER]						
S.No	01 = Once	02 = Twice	03 = Thrice	04 = More than thrice	99 = Don't know	01=Report 02=Self-report	
	01	02	03	04	99	01	02
	01	02	03	04	99	01	02
	01	02	03	04	99	01	02
	01	02	03	04	99	01	02
	01	02	03	04	99	01	02
	01	02	03	04	99	01	02
	01	02	03	04	99	01	02
	01	02	03	04	99	01	02
	01	02	03	04	99	01	02
	01	02	03	04	99	01	02
	Enumerator, check: Use supplementary sheet, if required, to record details of remaining household members. Supplementary sheet used (YES/ NO): Y / N						

Enumerator, check:

a. If PLUM installed in household – END. Complete D6, D7 on day of removing PLUM.
ଯଦି ଘରେ PLUM ଲଗାଯାଇଛି–ସାକ୍ଷାତକାର ବନ୍ଦକରନ୍ତୁ, D6, D7 ବିଭାଗକୁ PLUM କାଢିବା ଦିନ ପଚାରନ୍ତୁ ।

b. If non-PLUM household, CONTINUE with D6, D7.
ଯଦି ଘରେ PLUM ଲଗାଯାଇନାହିଁ D6, D7 ବିଭାଗକୁ ଚାଲୁରଖନ୍ତୁ ।

Enumerator guidance for D6, D7:

"Now I will request you to try to remember and tell me which members of your household used the latrine to defecate yesterday and the day before yesterday and approximately what time of the day they used it."

"I will show you one set of cards that depict the different times of day [IF REQUIRED, LAY OUT DAY PART CARDS IN SEQUENCE AND EXPLAIN, I.E. SUNRISE/MORNING (0400-1000 HR APPROXIMATELY), PRE-NOON/AFTERNOON (1000-1500 HR APPROXIMATELY), EVENING/SUNSET (1500-1900 HR APPROXIMATELY), NIGHT (1900-0400 HR APPROXIMATELY)] and a second set of images that represent members of your family [SHOW ONE MALE AND FEMALE EXAMPLE OF EACH AGE GROUP].

"Starting with the eldest family member [REFER TO LIST FROM D2 AND MATCH THE SERIAL NUMBER OF HOUSEHOLD MEMBER], please place the image of that member under the relevant time of day if he/she used the latrine at that time. If a family member used the latrine at multiple times in the day, please place copies of the image under the relevant day parts when he/ she used the latrine [REMOVE THE IMAGE ONCE COMPLETED AND REPEAT THE PROCESS FOR THE NEXT FAMILY MEMBER]. If the family member did not use the latrine or you don't know, please say so."

[IF A FAMILY MEMBER DID NOT USE THE LATRINE OR RESPONDENT DID NOT KNOW, MAKE A NOTE AND CONTINUE WITH THE NEXT FAMILY MEMBER AS LISTED IN D2].

ବର୍ତମାନ ମୁଁ ଆପଣଙ୍କୁ ଅନୁରୋଧ କରିବି ଆପଣଟିକେ ମନେପକାଇବାକୁ ଚେଷ୍ଟାକରି କୁହନ୍ତୁ କି ଘରର କେଉଁ ସଦସ୍ୟମନେ ଗତକାଲି ଏବଂ ତା'ପୁର୍ବ ଦିନର କେଉଁ କେଉଁ ସମୟରେ ଝାଡା ଯିବାପାଇଁ ପାଇଖାନା ବ୍ୟବହାର କରିଥିଲେ ?

ମୁଁ ଆପଣଙ୍କୁ କିଛି କାର୍ଡ ଦେଖାଇବି ଯାହା ଦିନର ଭିନ୍ନ ସମୟକୁ ଦର୍ଶାଇବ, କାର୍ଡଗୁଡିକୁ କ୍ରମାନୁସାରେ ସଜାଅ– (ସକାଳ/ସର୍ଯ୍ୟୋଦୟ–ସକାଳ ୪.୦୦–୧୦.୦୦), (ପୂର୍ବାହ୍ନ/ଅପରାହ୍ନ– ୧୦.୦୦–୩.୦୦), (ସଂନ୍ଧ୍ୟା/ସୂର୍ଯ୍ୟାସ୍ତ–୩.୦୦–୭.୦୦), (ରାତ୍ର–୭.୦୦–୪.୦୦).ଏବଂ ଅନ୍ୟ କିଛି ଚିତ୍ର ଦେଖାଅ ଯାହା ପରିବାରର ସଦସ୍ୟଙ୍କୁ ଦର୍ଶାଇବ(ଗୋଟିଏ ପୁରୁଷ ଓ ଗୋଟିଏ ସ୍ତ୍ରୀ ଙ୍କ ଚିତ୍ର ଦେଖାଅ) ।

ପ୍ରଥମେ ପରିବାରର ବୟସ୍କ ବ୍ୟକ୍ତିଙ୍କୁ ନିଅନ୍ତୁ,ସମୟ ଦର୍ଶାଯାଉଥିବା ଚିତ୍ର ତଳେ ଝାଡାଯାଇଥିବା ସମୟ ଅନୁଯାଇ ବ୍ୟକ୍ତିର ଚିତ୍ରକୁ ରଖନ୍ତୁ । ଯଦି ପରିବାରର କୌଣସି ଏକ ବ୍ୟକ୍ତି ଗୋଟିଏ ଦିନରେ ଅଧିକାଂଶଥର ପାଇଖାନା ବ୍ୟବହାର କରିଥାନ୍ତି ତେବେ ତାଙ୍କୁ ଦର୍ଶାଉଥିବା ଚିତ୍ରକୁ ସମୟ ଚିତ୍ର ତଳେ ସଜାଇ ରଖନ୍ତୁ । ଥରେ ଶେଷ ହୋଇଗଲା ପରେ ଚିତ୍ରଗୁଡିକୁ ଉଠାଇନିଅନ୍ତୁ ଏବଂ ପରିବାରର ଅନ୍ୟ ବ୍ୟକ୍ତିଙ୍କ ପାଇଁ ପୁନଃ ବ୍ୟବହାର କରନ୍ତୁ । ଯଦି ପରିବାରର ସଦସ୍ୟମାନେ ପାଇଖାନା ବ୍ୟବହାର କରୁନାହାନ୍ତି କିମ୍ବା ଆପଣ ଯାଣିନାହାନ୍ତି ତେବେ ଦୟାକରି କୁହନ୍ତୁ ।

D6 For each member in your household, please tell us which members used the latrine for defecation ***yesterday*** and the approximate time of day that they used it, ***starting with the eldest.*** If they used the latrine more than once in one day part, please also try and remember the number of times they used it. [REFER TO THE APPROPRIATE CODE FOR THE NUMBER OF TIMES LATRINE USED AND ENTER IN RELEVANT CELL FOR EACH HOUSEHOLD MEMBER WHO USED THE LATRINE].

ଦୟାକରି ମତେ କହିବେ କି, ଘରର ପ୍ରତ୍ୟେକ ସଦସ୍ୟମାନଙ୍କ ଭିତରୁ ଯେଉଁମାନେ ଗତକାଲି ପାଇଖାନା ବ୍ୟବହାର କରିଥିଲେ ତାହାର ଆନୁମାନିକ ସମୟ ବିଷୟରେ କୁହନ୍ତୁ । ବୟସ୍କ ବ୍ୟକ୍ତିଙ୍କଠାରୁ ଆରମ୍ଭ କରନ୍ତୁ, ଯଦି ସେମାନେ ଏକ ରୁ ଅଧିକ ଥର ପାଇଖାନା ବ୍ୟବହାର କରିଥାନ୍ତି, ତେବେ ଦୟାକରି ମନେପକାଇବାକୁ ଚେଷ୍ଟାକରନ୍ତୁ କେତେଥର ବ୍ୟବହାର କରିଥିଲେ । ତଳେ ଦିଆଯାଇଥିବା କୋର୍ଡକୁ ଅନୁସରଣ କରନ୍ତୁ ଓ ସଠିକ୍ ସଦସ୍ୟଙ୍କ ସ୍ଥାନରେ ସମୟ ଅନୁଯାୟୀ ଲେଖନ୍ତୁ

S. No. (HH member)	Day parts				01=Report 02=Self-report	
	Sunrise/Morning (0400-1000 hr) 77=None, 01=Once, 02=Twice, 03=Thrice, 04=More than thrice, 99=Don't know	Pre-noon/ Afternoon (1000-1500 hr) 77=None, 01=Once, 02=Twice, 03=Thrice, 04=More than thrice, 99=Don't know	Evening/Sunset (1500-1900 hr) 77=None, 01=Once, 02=Twice, 03=Thrice, 04=More than thrice, 99=Don't know	Night (1900-0400 hr) 77=None, 01=Once, 02=Twice, 03=Thrice, 04=More than thrice, 99=Don't know		

D7	For each member in your household, please tell us which members used the latrine for defecation the ***<u>day-before yesterday</u>*** (NAME THE DAY OF THE WEEK) and the approximate time of day that they used it, ***starting with the eldest.*** If they used the latrine more than once in one day part, please also try and remember the number of times they used it. [REFER TO THE APPROPRIATE CODE FOR THE NUMBER OF TIMES LATRINE USED AND ENTER IN RELEVANT CELL FOR EACH HOUSEHOLD MEMBER WHO USED THE LATRINE]. ଦୟାକରି ମତେ କହିବେ କି, ଘରର ପ୍ରତ୍ୟେକ ସଦସ୍ୟମାନଙ୍କ ଭିତରୁ ଯେଉଁମାନେ ଗତକାଲିର ପୂର୍ବଦିନ(ଦିନର ନାମ) ପାଇଖାନା ବ୍ୟବହାର କରିଥିଲେ ତାହାର ଆନୁମାନିକ ସମୟ ବିଷୟରେ କୁହନ୍ତୁ । ବୟସ୍କ ବ୍ୟକ୍ତିଙ୍କଠାରୁ ଆରମ୍ଭ କରନ୍ତୁ, ଯଦି ସେମାନେ ଏକ ରୁ ଅଧିକ ଥର ପାଇଖାନା ବ୍ୟବହାର କରିଥାନ୍ତି, ତେବେ ଦୟାକରି ମନେପକାଇବାକୁ ଚେଷ୍ଟାକରନ୍ତୁ କେତେଥର ବ୍ୟବହାର କରିଥିଲେ । ତଳେ ଦିଆଯାଇଥିବା କୋର୍ଡକୁ ଅନୁସରଣ କରନ୍ତୁ ଓ ସଠିକ୍ ସଦସ୍ୟଙ୍କ ସ୍ଥାନରେ ସମୟ ଅନୁଯାୟୀ ଲେଖନ୍ତୁ

S. No. (HH member)	Day parts				01=Report 02=Self-report	
	Sunrise/Morning (0400-1000 hr) 77=None, 01=Once, 02=Twice, 03=Thrice, 04=More than thrice, 99=Don't know	Pre-noon/ Afternoon (1000-1500 hr) 77=None, 01=Once, 02=Twice, 03=Thrice, 04=More than thrice, 99=Don't know	Evening/Sunset (1500-1900 hr) 77=None, 01=Once, 02=Twice, 03=Thrice, 04=More than thrice, 99=Don't know	Night (1900-0400 hr) 77=None, 01=Once, 02=Twice, 03=Thrice, 04=More than thrice, 99=Don't know		

HH ID: __ __ __ __ __ __

MODULE E: PLUM WORKSHEET							
Latrine no. (as in B8)	**PLUM ID**	**Network coverage** (Y/N)	**Installation**		**Removal**		**Remarks**
			Date (dd/mm/yyyy)	**Time** (hh:mm)	**Date** (dd/mm/yyyy)	**Time** (hh:mm)	
			Enumerator’s signature		Enumerator’s signature		

HH ID: __ __ __ __ __ __

MODULE F: GPS RECORDINGS – WATER SOURCES AND LATRINE-HOUSE DISTANCE

Enumerator: Use handheld GPS devices to measure and record the following distances. If distance appears to be 30 meters or less, also record the distance using measuring tape.

F1. DISTANCE OF LATRINE FROM WATER SOURCES

F1 A. LATRINE (L) AND LATRINE WATER SOURCE (LWS)

	LWS1 (GPS ID 1)			LWS2 (GPS ID 1)			LWS3 (GPS ID 1)		
	GPS		Dist. (mtr)	GPS		Dist. (mtr)	GPS		Dist. (mtr)
	ID 1	ID 2		ID 1	ID 2		ID 1	ID 2	
Latrine no.1 (GPS ID 2)									
Latrine no.2 (GPS ID 2)									
Latrine no.3 (GPS ID 2)									

F1 B. LATRINE (L) AND BATHING WATER SOURCE (BWS)

	BWS1 (GPS ID 1)			BWS2 (GPS ID 1)			BWS3 (GPS ID 1)		
	GPS		Dist. (mtr)	GPS		Dist. (mtr)	GPS		Dist. (mtr)
	ID 1	ID 2		ID 1	ID 2		ID 1	ID 2	
Latrine no.1 (GPS ID 2)									
Latrine no.2 (GPS ID 2)									
Latrine no.3 (GPS ID 2)									

F2. DISTANCE BETWEEN LATRINE AND HOUSE

Enumerator: Measure and record the distance between the closest exit door to the latrine and the latrine.

	Latrine no.1 (GPS ID 1)			Latrine no.2 (GPS ID 1)			Latrine no.3 (GPS ID 1)		
	GPS		Dist. (mtr)	GPS		Dist. (mtr)	GPS		Dist. (mtr)
	ID 1	ID 2		ID 1	ID 2		ID 1	ID 2	
House (GPS ID 2)									

HH ID: __ __ __ __ __ __

MODULE G: DEMOGRAPHIC AND SOCIO-ECONOMIC STATUS				
Enumerator, check: This module is to only be completed for NEW HOUSEHOLDS that have been added after baseline, for example, split households etc.				
G1	Gender of the head of household ଘରର ମୁଖିଆଙ୍କର ଲିଙ୍ଗ କଣ ?	Male Female	01 02	
G2	Highest level of education that the head of household has attained ଘରର ମୁଖିଆଙ୍କର ସର୍ବାଧିକ ଶିକ୍ଷାଗତ ଯୋଗ୍ୟତା କେତେ ?	Illiterate Literate without formal schooling Less than primary school (attended school, not completed 5^{th} year) Completed primary (5^{th} year passed, not 10^{th}) Secondary (10^{th} passed, not 12^{th}) Completed +2 year (12^{th} passed, not graduation) Graduation and above Don't know	01 02 03 04 05 06 07 99	
G3	Highest level of education that the primary child care giver has attained ଶିଶୁଙ୍କର ଯତ୍ନ ନେଉଥିବା ମହିଳାଙ୍କର ଶିକ୍ଷାଗତ ଯୋଗ୍ୟତା କେତେ ?	Illiterate Literate without formal schooling Less than primary school (attended school, not completed 5^{th} year) Completed primary (5^{th} year passed, not 10^{th}) Secondary (10^{th} passed, not 12^{th}) Completed +2 year (12^{th} passed, not graduation) Graduation and above Don't know	01 02 03 04 05 06 07 99	
G4	What is the caste or tribe of the head of the household? ପରିବାରର ମୁଖ୍ୟଙ୍କର ଜାତି କଣ ?	Scheduled caste Scheduled tribe Other backward caste Other caste Don't know	01 02 03 04 99	
G5	How many rooms in the house are used for sleeping? ଗୃହ ମଧ୍ୟରେ କେତୋଟି କୋଠରୀକୁ ଶୋଇବା ନିମନ୍ତେ ବ୍ୟବହାର କରାଯାଏ ? [RECORD IN DIGITS]		__ __	

G6	*Observe and record* Type of house କେଉଁ ପ୍ରକାର ଘର	Pucca (walls AND roof made of cement) Semi-pucca (only ONE of the two is made of cement and bricks) Kuchha (walls and roof NOT made of cement)	01 02 03		
G7	What is the principal source of lighting for your household? ଗୃହକୁ ଆଲୋକିତ କରିବା ପାଇଁ ମୁଖ୍ୟ ବ୍ୟବସ୍ଥା କଣ ?	Electricity Kerosene Gas Oil Other (specify)	01 02 03 04 88		
G8	What type of fuel does your household <u>mainly</u> use for cooking? ଆପଣଙ୍କ ପରିବାର ନିମନ୍ତେ ମୁଖ୍ୟତଃ କେଉଁ ପ୍ରକାର ବ୍ୟବସ୍ଥା ଅଛି ?	Electricity LPG/ Natural gas Biogas Kerosene Coal/ Lignite Charcoal Wood Agricultural crop waste Dung cakes Other (specify)	01 02 03 04 05 06 07 08 09 88		
G9	Where does the cooking normally take place? ସାଧାରଣତଃ କେଉଁଠି ରୋଷେଇ କରାଯାଏ ?	Inside house, separate room Inside house, no separate room In separate building Outdoors Other (specify)	01 02 03 04 88		
	Does any member of your household own the following items? ଆପଣଙ୍କ ପରିବାରର କୌଣସି ସଦସ୍ୟଙ୍କର ଏହି ସବୁ ସାମଗ୍ରୀ ଅଛି କି ?		Yes	No	
G10	Watch or clock		01	02	
G11	Pressure cooker		01	02	
G12	Telephone		01	02	
G13	Television		01	02	
G14	Refrigerator		01	02	
G15	Radio		01	02	
G16	Chair		01	02	
G17	Mattress		01	02	
G18	Cot or bed		01	02	
G19	Table		01	02	
G20	Electric fan		01	02	
G21	Sewing machine		01	02	

G22	Water pump		01	02	
G23	Bicycle		01	02	
G24	Motorbike/ Scooter		01	02	
G25	Car		01	02	
G26	Animal drawn cart		01	02	
G27	Thresher		01	02	
G28	Tractor		01	02	
G29	Does your family own agricultural land? ଆପଣଙ୍କ ପରିବାରର ଋଷ ଜମି ଅଛି କି ?	Yes, non-irrigated land only Yes, some irrigated land No land	01 02 03		
G30	Does anyone in your household own poultry/ livestock or farm animals? ଆପଣଙ୍କ ପରିବାରର କୌଣସି ସଦସ୍ୟଙ୍କର କୁକୁଡା/ଗାଇଗୋରୁ କିମ୍ବା ଅନ୍ୟ କିଛି କୃଷି ସହଯୋଗକାରୀ ପଶୁ ଅଛନ୍ତି କି ?	Yes No	01 02		 Skip to G32
G31	How many of the following does your household own? ଆପଣଙ୍କ ପରିବାରରେ ପାର୍ଶ୍ୱଲିଖିତ ପଶୁ ସମ୍ପଦ ମାନଙ୍କ ମଧ୍ୟରୁ କେଉଁଥିରୁ କେତୋଟି ଅଛି ?	Cattle Buffalo Goats Sheep Chicken Pigs	__ __ __ __ __ __ __ __ __ __ __ __		
G32	Does your household own a BPL card? ଆପଣଙ୍କ ପରିବାରରେ ବି.ପି.ଏଲ୍. କାର୍ଡ ଅଛି କି ?	Yes, verified Yes, not verified No	01 02 03		

HH ID: __ __ __ __ __ __

LIST OF HOUSEHOLD MEMBERS:

Age and gender of each member living in the household. [LIST FROM OLDEST TO YOUNGEST]				
S No.	Name	Age (years)	Male	Female
1		__ __	01	02
2		__ __	01	02
3		__ __	01	02
4		__ __	01	02
5		__ __	01	02
6		__ __	01	02
7		__ __	01	02
8		__ __	01	02
9		__ __	01	02
10		__ __	01	02
11		__ __	01	02
12		__ __	01	02
13		__ __	01	02
14		__ __	01	02
15		__ __	01	02
16		__ __	01	02
17		__ __	01	02
18		__ __	01	02
19		__ __	01	02
20		__ __	01	02

HH ID: __ __ __ __ __ __

SUPPLEMENTARY SHEET

D1	CONTINUED For each member in your household, please tell us the name, age, gender and ***usual*** place of defecation (through the year) starting ***with the eldest.***												
Sl.No	Name	Age	Gender 01 = M 02 = F		Usual place of defecation 01 = Latrine always 02 = Latrine usually 03 = Latrine sometimes 04 = Open defecation always 05 = Defecation within household compound always 88 = Other (specify)						01 = Report 02 = Self-report	
11			01	02	01	02	03	04	05	88	01	02
12			01	02	01	02	03	04	05	88	01	02
13			01	02	01	02	03	04	05	88	01	02
14			01	02	01	02	03	04	05	88	01	02
15			01	02	01	02	03	04	05	88	01	02
16			01	02	01	02	03	04	05	88	01	02
17			01	02	01	02	03	04	05	88	01	02
18			01	02	01	02	03	04	05	88	01	02
19			01	02	01	02	03	04	05	88	01	02
20			01	02	01	02	03	04	05	88	01	02
21			01	02	01	02	03	04	05	88	01	02
22			01	02	01	02	03	04	05	88	01	02
23			01	02	01	02	03	04	05	88	01	02
24			01	02	01	02	03	04	05	88	01	02
25			01	02	01	02	03	04	05	88	01	02

HH ID: __ __ __ __ __ __

SUPPLEMENTARY SHEET

D5	CONTINUED: Among your family members who use the latrine, can you tell me how many times in the day they usually use the latrine? ଆପଣଙ୍କ ପରିବାରର ଯେଉଁମାନେ ପାଇଖାନା ବ୍ୟବହାର କରନ୍ତି,ସେମାନେ ଦିନକୁ କେତେ ଥର ବ୍ୟବହାର କରନ୍ତି ଦୟାକରି କହବେକି ? [REFER TO LIST FROM D2 AND MATCH THE SERIAL NUMBER/ NAME OF HH MEMBER]						
S.No	01 = Once	02 = Twice	03 = Thrice	04 = More than thrice	99 = Don't know	01=Report 02=Self-report	
	01	02	03	04	99	01	02
	01	02	03	04	99	01	02
	01	02	03	04	99	01	02
	01	02	03	04	99	01	02
	01	02	03	04	99	01	02
	01	02	03	04	99	01	02
	01	02	03	04	99	01	02
	01	02	03	04	99	01	02
	01	02	03	04	99	01	02
	01	02	03	04	99	01	02
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	01	02	03	04	99	01	02
	01	02	03	04	99	01	02
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	01	02	03	04	99	01	02
	01	02	03	04	99	01	02
	01	02	03	04	99	01	02

APPENDIX 2


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Combining sensor monitoring and ethnography to evaluate household latrine usage in rural India

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ABSTRACT

This paper advances research on methods used to evaluate sanitation usage and behavior. The research used quantitative and qualitative methods to contribute to new understanding of sanitation practices and meanings in rural India. We estimated latrine usage behavior through ethnographic interviews and sensor monitoring, specifically the latest generation of infrared toilet sensors, Portland State University Passive Latrine Use Monitors (PLUMs). Two hundred and fifty-eight rural households in West Bengal (WB) and Himachal Pradesh, India, participated in the study by allowing PLUMs to be installed in their houses for a minimum of 6 days. Six hundred interviews were taken in these households, and in others, where sensors had not been installed. Ethnographic and observational methods were used to capture the different defecation habits and their meanings in the two study sites. Those data framed the analysis of the PLUM raw data for each location. PLUMs provided reliable, quantitative verification. Interviews elicited unique information and proved essential to understanding and maximizing the PLUM data set. The combined methodological approach produced key findings that latrines in rural WB were used only for defecation, and that low cost, pit latrines were being used sustainably in both study areas.

Key words | behavior change, ethnography, India, policy, sanitation, sensor monitoring

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INTRODUCTION

While Indian sanitation policy is increasing coverage in rural areas through state-funded, social marketing, and behavior change approaches, toilets are not necessarily being used. Individual household latrines (IHLs) are converted to storage units, animal housing, or are neglected entirely (O'Reilly 2010). Toilets are only sporadically/seasonally used, or are used by some family members and not others (Coffey *et al.* 2014). Toilets are used in ways that are unsanitary and fail to reduce in disease (Montgomery *et al.* 2010; Jenkins *et al.* 2014). The process of becoming a toilet user remains little understood, in part because of the myriad factors and processes that play a role in toilet adoption (Waterkeyn & Cairncross 2005; Joshi *et al.* 2011; Barnard *et al.* 2013; O'Reilly & Louis 2014). Furthermore, sanitation studies have yet to resolve the question of how to measure toilet usage with accuracy and sensitivity, leaving open the question of whether current policy is effective (Cousens *et al.* 1996; Rodgers *et al.* 2007). As Thomas *et al.* (2013) recommended, more rigorous, innovative evaluations are needed to guide best practices and improve future programs. Without clarity on why sanitation is adopted in some places and not others, programing and policy development is made more difficult.

This paper intends to fill a gap in studies of rural sanitation by demonstrating the combined strengths of quantitative and qualitative methods. We used Passive Latrine Use Monitors (PLUMs; instrumented monitoring) to quantify toilet usage. We used ethnography to learn about users, their beliefs about sanitation, and how beliefs influenced practices (Rheinländer *et al.* 2010). Ethnography is judged methodologically by different criteria than quantitative methods (Small 2009), leading to some tensions in research design. However, combining the two methods enabled insights into everyday sanitation

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behavior, including key findings that: (1) toilets across the WHO/UNICEF Joint Monitoring Program for Water Supply and Sanitation spectrum were sustainably used in both study areas; and (2) beliefs of impurity limited toilet use to defecation in West Bengal (WB). We discuss these findings below, after a brief review of the literature.

UNDERSTANDING AND MONITORING SANITATION ADOPTION

Studies deploying ethnographic methods, especially in-depth interviews, have uncovered a number of non-health-related reasons motivating toilet building, e.g., social prestige, protection of women family members, desire to be modern, desire to take advantage of something given with little opportunity cost to the family, and rising household incomes (Srinivas 2002; Jenkins 2004; Jenkins & Curtis 2005; O'Reilly & Louis 2014). Interviews and focused group discussions have illuminated geographic variations in meanings of waste and hygiene; local norms for gendered, age-relevant defecation practices; and socio-religious rules about waste disposal matter for sanitation uptake (Mcfarlane 2008; O'Reilly 2010; Drangert & Nawab 2011). As Rheinländer *et al.* (2010) argued, knowledge of communities' beliefs about defecation is critical, as practices derive from beliefs. Insights into beliefs, values, and meanings may be learned by asking people about them, and by observing their practices as a reflection of their beliefs. We used ethnography to illuminate geographically specific toilet use behaviors and the beliefs behind them.

Researchers have tackled the problem of assessing toilet usage (e.g., Olsen *et al.* 2001; Montgomery *et al.* 2010), but as yet, no single observational solution manages to be accurate, sensitive, and non-intrusive. Structured observation at peak times of toilet usage is intrusive and may alter users' behavior (Ram *et al.* 2010; Clasen *et al.* 2012). It is also time-consuming, costly, and therefore difficult to scale up, while only providing a limited snapshot of potentially biased behavior. Observational methods such as looking for fresh feces in the pit or in open defecation areas, presence of materials for anal cleansing, and/or a wet toilet floor are subjective, lack sensitivity and specificity, and may be impossible given the toilet technology (Clasen *et al.* 2012). Self-reporting is also problematic as individuals may over-report in an effort to please the data collector, and gender of the evaluator has been shown to cause under-reporting (Manun'Ebo *et al.* 1997).

Cellular phone network-based monitoring technology has been field-tested to record usage and behavior change in WASH and other public health interventions, e.g., the provision of household water filters, hand washing stations, and cookstoves (Thomas *et al.* 2013). Effective use of remote monitoring is made possible by improved cellular networks, low cost of electronic components, and improved battery technology (Thomson *et al.* 2012; Thomas *et al.* 2013). The main argument for using electronically instrumented monitoring technologies is that they provide cost-effective, objective, accurate, regular, and continuous data thereby filling a critical gap in the ability to monitor health interventions effectively (Clasen *et al.* 2012; Thomas *et al.* 2013).

Below we discuss the study site and population selection rationale before moving into the specific methods guiding the quantitative and qualitative portions of the research. An analytical section follows, including a description of our iterative process, and discussion of findings. We conclude that, despite the challenges of integrating disparate methodological tools, combined methods offer new understandings of sanitation behavior in rural India.

SITE SELECTION AND STUDY POPULATION

Our goal was to contribute new insights into effective sanitation by studying unique places where sanitation was adopted at rates of almost 100% in parts of rural India. Therefore, the research was conducted in rural village areas of WB and Himachal Pradesh (HP) – two geographically and economically different states that have made some of the greatest improvements in sanitation coverage in the past 20 years (Table 1).

Table 1 | Percentage of households without toilets in WB and HP – 1992/93 to 2011

State	1992/93[1]	2001[2]	2011[2]
WB	59.6	56.3	41.2
HP	87.4	66.6	30.9
All India	69.7	63.6	53.1

Source: [1]NFHS-1 and NFHS-2 (National Family Health Survey), India. www.nfhsindia.org.
[2]Census of India, 2011.

We chose Gram Panchayats (GPs; i.e., political subdivisions comprising multiple small villages) that won the Clean Village Award (NGP; a cash award for open defecation free status) in the past 3–5 years and that were well-known locally and extra-locally as areas of high toilet usage. Selected GPs were of mixed caste and class composition to enable a broad, socio-demographic cross-section of participants. Several IHL types were observed at each site; most were improved sanitation (Table 2). Toilet cabins ranged from plastic sheeting to brick and mortar walls with slab roofs. Almost all toilets were built at a distance from the main dwelling. In HP, some households had attached (to the house) toilets in a room large enough for bathing (hereafter, toilet/bathroom).

The field team in WB comprised the second author and two local research assistants who worked from September to December 2012. The field team in HP comprised the second author, one of the WB research assistants, and two local assistants working from January to March 2013. The first author was on site for the first month of the field period in each state. All teams were fluent in Hindi; local assistants spoke the local language(s). The villages and informants were given pseudonyms. Interviews took place after participants were informed of the research goals, work plan, and consent documents. The research was approved by the Texas A&M Office of Research Compliance Institutional Review Board.

Table 2 | Socio-demographics of households interviewed

	All	WB1	WB2	HP1	HP2
Number of households	607	150	156	151	150
Age of interviewees					
18–24	44	15	13	3	13
25–30	59	18	15	8	18
31–35	74	20	19	17	18
36–40	76	23	18	17	18
41–45	60	21	15	14	10
46–50	75	19	19	19	18
51–55	54	13	13	18	10
>55	165	21	44	55	45
Gender of interviewees					
Female	286	70	70	74	72
Male	327	80	84	78	85
Marital status					
Married	547	141	147	133	126
Single	25	1	5	5	14
Widowed	35	8	4	13	10
Divorced/separated	0	0	0	0	0
Education					
Illiterate	100	34	32	14	20
Did not complete primary school	66	28	26	6	6
Completed primary school	43	14	8	7	14
Some secondary school	240	57	69	76	38
Completed high school	83	5	9	24	45
In or completed college	75	12	12	24	27
Sanitation facility					
No facility	2	0	0	0	2
Pit latrine without slab	2	2	0	0	0
Pour flush to pit latrine (cement pan or *kaccha toilet*)	172	70	98	1	3
Pour flush to pit latrine (porcelain pan or *pucca toilet*)	428	77	58	150	143
Shared toilet	3	1	0	0	2
Water scarcity					
2–4 months	35	0	0	30	5
None	572	150	156	121	145

QUANTITATIVE METHODS

Sensor monitoring

The technology employed in this study, Portland State University PLUMs, is described in technical detail in other publications, including Thomas *et al.* (2013). A simple infrared motion detector was used, identical to the commercial sensor selected in the Clasen *et al.* (2012) study. A comparator circuit was linked with the motion detector, and recorded each detected motion. One or more times per day, the comparator board relayed logged data events to the internet via GSM cellular technology. A handheld cell phone was used to determine if a signal could be located at the household, indicating the PLUM could communicate with the cell phone tower. If a strong signal was unavailable, it was switched into local logging mode on a micro-SD card and data were manually uploaded after removal from the toilet. PLUMs were fastened with zip ties (also known as cable ties) within 5 feet of the toilet pan.

Forty PLUMs were utilized and were rotated between 291 households. In related studies, PLUMs suggested low behavioral reactivity after the first several days, so PLUMs were installed for 7–10 days to capture behavior for at least 6 days of data. PLUM installations occurred based on willingness to accept, and the presence of the household head. The PLUM installation sample illustrates one of the tensions arising from combining qualitative and quantitative methods: we do not claim a representative, random, or unbiased sample of households with PLUMs installed. Ethical obligations prevented the installation of PLUMs in households that refused them, which may have biased the data if refusal was due to toilet non-use. However, respondents were forthcoming in interviews about household members who went for open defecation whether they accepted PLUMs or not, nor was there a noticeable difference in PLUM acceptance across the study sites once we routinized our installation strategy. Informants' honesty also enabled us to better calculate the number of toilet users per household, refining PLUM data analysis. It is possible that interviewing before installation and the initial presence of the PLUM may have influenced household behavior. This potential reactivity has not been rigorously characterized to date.

The PLUM online software system contains several data correction, reduction, and analysis routines. Subsequently, an R code is run to interpret the raw data and generate estimates of 'usage events'. The algorithm employed is largely based on Clasen *et al.* (2012), with some adjustments to account for technological differences between the sensors. To validate the adjusted interpretation algorithm, the current technology (SweetSense PLUM; third generation) was deployed alongside the earlier, validated technology (2G PLUMs; second generation) in 11 household latrines conducted outside the research study environment, in rural communities in Orissa, India in the fall of 2013 (Sinha in preparation). A Bland Altman comparison, a method commonly used to analyze agreement between two different measurement methods (2G PLUMs v. SweetSense (SS) PLUMs) of the same parameter, is shown in Figure 1. The mean difference between usage events detected by both 2G and SS PLUMs of 2.3 events per household per day is represented by the horizontal solid line with the differences from the mean shown in a scatter plot. The comparison indicated agreement, on

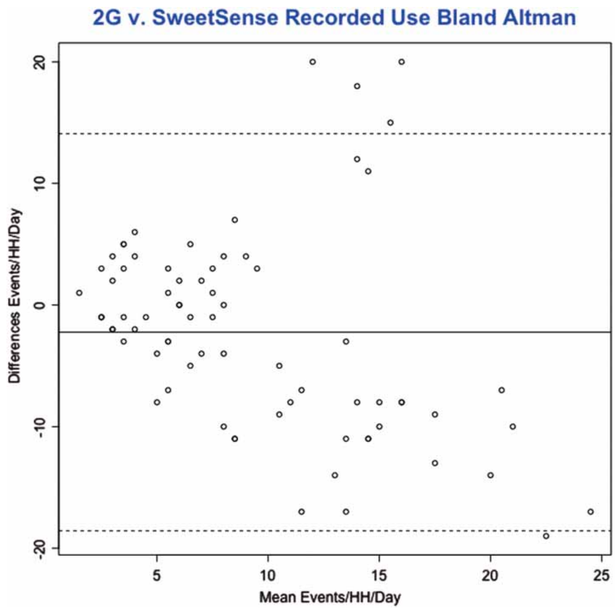

Figure 1 | Bland Altman Test: 2G PLUMs versus SweetSense PLUMs recorded use.

average, between the two technologies, but with a large standard deviation. The large standard deviation of approximately eight usage events per household per day suggested that an additional comparative method was required to have confidence in the comparability of these two technologies.

Therefore, a secondary data source was used consisting of structured observations, also in Orissa, India. The structured observations included deploying both versions of the PLUMs and having an observer manually record use of each latrine (Figure 2). First, each sensor-detected event was compared against the temporally nearest manually observed event, allowing for an evaluation of error associated with over-reporting events, or false positives ('o' scatter plot and associated line fit). The converse was then applied, comparing each manually observed event against the temporally nearest sensor-detected event, indicating error associated with under-reporting, or false negatives ('x' scatter plot and associated line fit). The axes are shown in Unix seconds (seconds since 1 January 1970) for ease of computational analysis. The analysis shows near perfect agreement between the observed and sensor-detected events, with only three outliers. Two 'o's (overlaying each other) show observed events that were not closely aligned with sensor events. One 'x' is the converse. The sample size of the observed versus recorded events

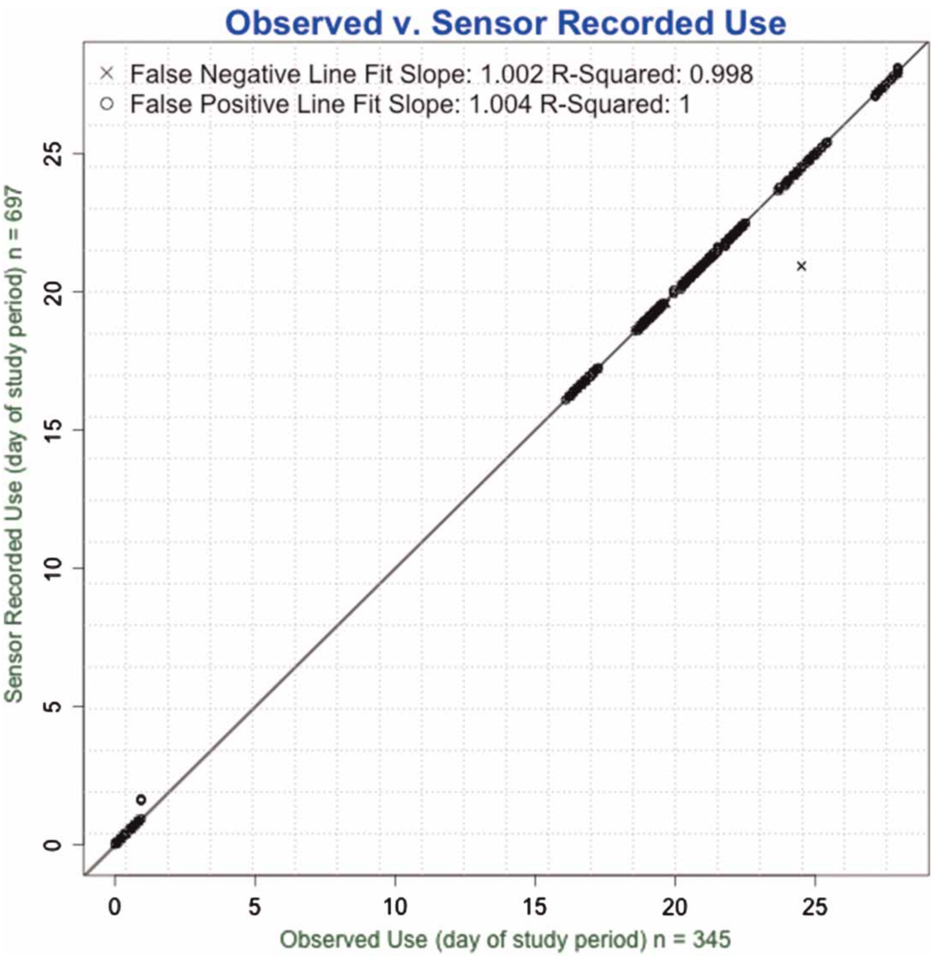

Figure 2 | Structured observed use versus sensor recorded toilet use.

are different because the sensors were in place considerably longer than the observers, leading to a greater number of sensor events available for the correlation analysis. These results suggest that the latest generation of PLUM sensors interpret usage events in a method substantially similar to the earlier, validated, technology.

QUALITATIVE METHODS

Ethnography

We conducted over 600 in-depth semi-structured interviews with household members and key informants. The rationale for 600 interviews was to ensure saturation (i.e., interviews produced no new data) and to interview across socio-economic characteristics and toilet type in each of the four GPs (see Table 2). We only interviewed in households where toilets were present and householders reported that they were being used. Respondents were adults, but not necessarily the household head. Household interviews covered: family composition, general usage, household toilet building history, and their understandings of human waste, sanitation, and hygiene. We did not ask respondents about their usage habits because we found early in the field period that respondents grew suspicious that we were 'checking' (i.e., official record keeping that may have negative repercussions for households) on toilet usage. Households were reassured that we were not checking, but seeking to confirm our information that these were GPs where most households used their toilets.

This strategy of reassuring interviewees highlights again the tensions between qualitative and quantitative methods – in order to allay subjects' fears, the research team informed subjects of the research goals in ways that may have biased their answers. The size of the interview sample may have compensated for bias, but ethnography also depends on the research team's ability to sense if informants lie or prevaricate. We omitted such interviews from our analysis. Once PLUMs were installed, the time and date of installation was logged in a field notebook. At the final study site, on the day the PLUM was removed, interviewees were questioned about their toilet use habits of the day before. It was only after extensive fieldwork that we felt confident that (1) we could install PLUMs even if we asked about individual usage and (2) that asking would not bias PLUM data beyond expected reactivity.

The research team lived in the GPs while the research was conducted. This facilitated unstructured participant observation events in the form of multiple, informal visits to households to observe household sanitation practices and to triangulate interviews and PLUM data. We also assembled participant households' photographic data sets of toilet type, cabin construction, PLUM installation, and path to toilet from house. Fieldnotes on unstructured participant observation and interview transcripts were coded by recurring themes and analyzed for significant patterns. Household socio-economic data were entered into a spreadsheet. The photographic record was organized by household and referred back to during the iterative analytical process described in the Discussion section. Key informant interviews were used to create a history of sanitation interventions for each study site. After the first round of PLUM data analysis, the research team returned to the field during September 2013 for results' dissemination with stakeholders. We now turn to results and a discussion of findings from each method and as part of an iterative process.

RESULTS

Qualitative results

The detailed ethnographic results have been published elsewhere (O'Reilly & Louis 2014). In brief, successful sanitation depended on three factors: political will, political ecology, and proximate social pressure. Each forms one leg of the 'toilet tripod,' united by political economy – the 'seat' of the toilet tripod. Political will encompassed long-term, multi-scalar government and NGO (Non-Governmental Organization) efforts to facilitate toilet building and usage. Political ecology included the complex human–environment relationships that changed over time to support toilet adoption. Proximate social pressure comprised the informal encounters that influenced neighbors and family members to build and use toilets. All four study sites had different economies, types of government intervention, NGO involvement, and environmental resources. Nevertheless, the framework of the toilet tripod comprehended the success of sanitation in each location. Below we address specific behavior, values, and patterns that emerged through combining ethnography and sensor monitoring.

Quantitative results

Of the 291 household data sets, a total of 258 households' data were included in the analysis. These households had PLUM readings for at least 6 days. Thirty-three households were excluded for having less than 6 days of data, usually due to PLUM failure, and occasionally because households covered or removed PLUMs. A specialized R code for this study parsed interpreted sensor data for each household deployment across the four sites. For each sensor, outliers were removed based on 1.5 times the interquartile range for that data set, a standard outlier removal approach (Weinberg & Abramowitz 2002). For per person usage calculations, the algorithm relied on recorded household toilet user data. Children too young to use a toilet were not counted, as their feces were not generally disposed of in IHLs (O'Reilly & Louis 2014).

The data sets at each site were not normally distributed, likely due to clustered low-end recorded behavior. The total aggregate recorded per person use is shown in a histogram (Figure 3). Therefore, groups were compared using the Wilcox ranked sum test that is less sensitive to non-normal data than the *t*-test. The Wilcox ranked sum difference may be interpreted as a comparable mean difference value as often presented in a *t*-test. Figure 4 and Table 3 show the mean per capita usage events at each of the four sites.

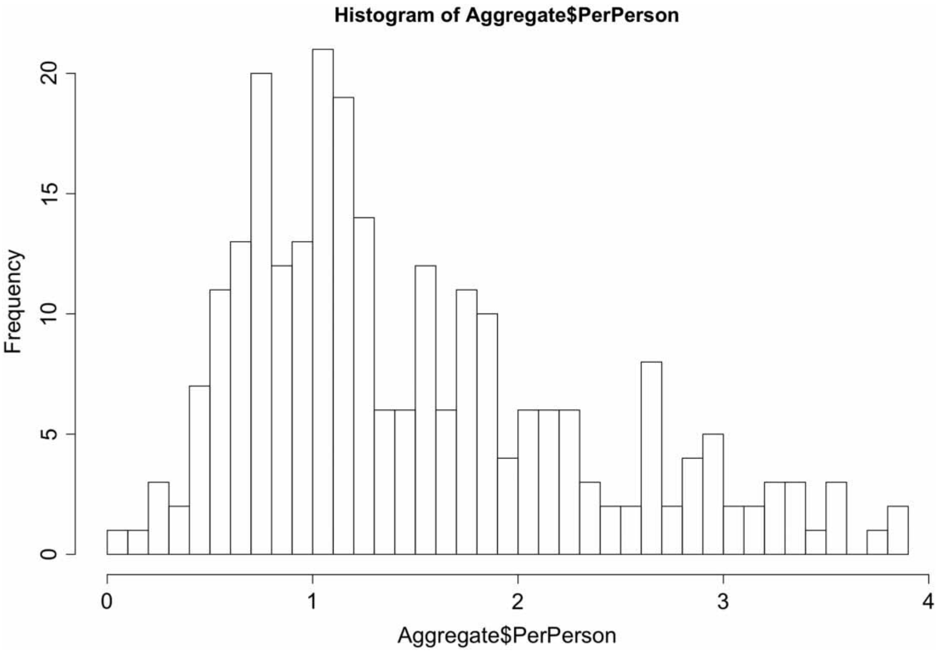

Figure 3 | Histogram of aggregate per person per day latrine use.

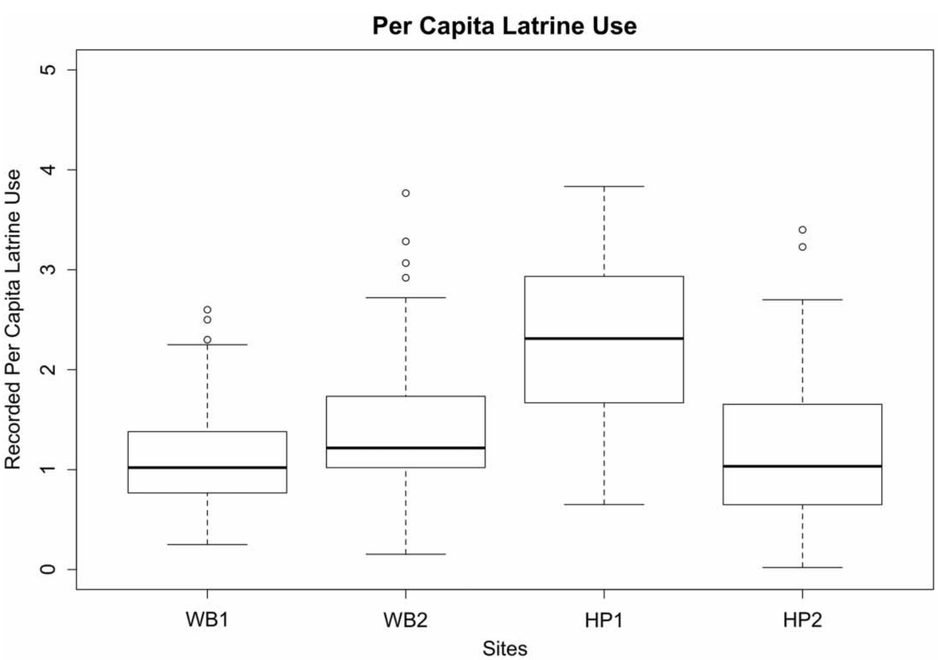

Figure 4 | Per capita latrine use per day by GP.

Table 3 | Mean per capita per day latrine use based on PLUM data by GP and state

GP	Recorded per capita use	Wilcox ranked sum difference
WB	1.29	
WB1	1.14	0.25
WB2	1.46	
HP	1.71	
HP1	2.27	1.13
HP2	1.18	
Overall average	1.51	

According to Clasen *et al.* (2012), a 3 minute separation between usage events was arbitrarily chosen for the algorithm. We repeated this 3 minute separation between usage events. If separate usage events occurred within less than 3 minutes of each other, the algorithm would analyze them as one usage event. Thus, under-reporting during high traffic times may occur with the current analytical algorithm.

Across all four study sites, usage frequency per capita per day averaged 1.51, which is in keeping with norms for Western and non-Western populations (Palit *et al.* 2012). There was a slightly significant difference between WB1 (1.14) and WB2 (1.46), of about 0.245 uses per person per day. Between the two states, there was slight significance for WB (1.29) and HP (1.71) of about 0.34 uses per person per day. No statistically significant differences in per capita usage events by study site were recorded with the exception of the two sites within HP. The influence of the high per capita toilet use in HP1 likely influenced both the state differences *and* the intra-HP differences.

DISCUSSION

In this section, we discuss the insights on mean per capita usage, toilet type, and time of day of usage gained by using combined quantitative and qualitative methods.

Mean per capita usage

Initially, the data analysis suggested that WB2 per capita toilet usage was lower than WB1, but interviews led us to expect that WB2 toilet use should have been the same or higher. In WB2, the majority of households owned toilets for more than 10 years, while in WB1 the majority owned toilets for less than 10 years (see Figure 5). Length of time of sustained intervention and toilet ownership meant that WB2 informants were more likely than those in WB1 to speak in terms of having a 'toilet habit'. We recalculated PLUM installations using fractions of days (as recorded in fieldnotes) to get a more accurate per capita reading than the initial calculation that used whole numbers for days reported. With this adjustment, WB2 (1.46) per capita use was higher than WB1 (1.14) – a slight significant difference. Ethnography alerted us to subtleties in reported toilet usage within NGP villages, and the discrepancy between partial days and full days of installation for PLUM analysis.

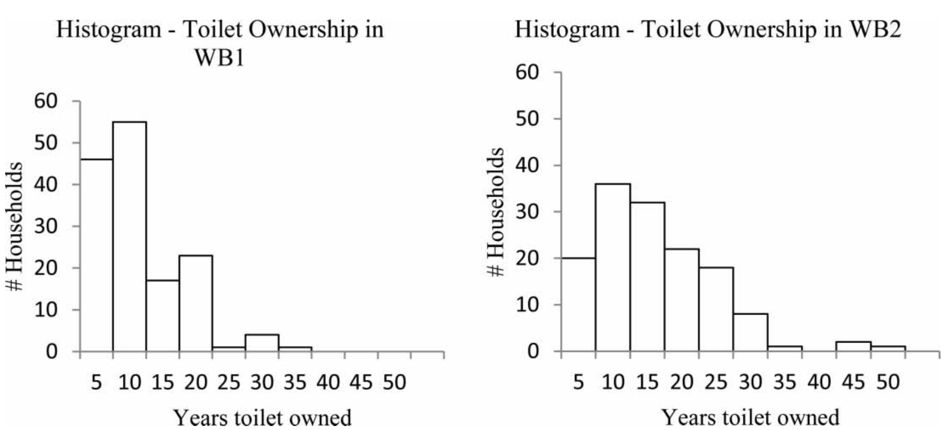

Figure 5 | Histogram of toilet ownership in WB.

The differences in mean per capita toilet usage between WB and HP were expected. In WB1 and WB2, toilets were only used for defecation and bathing after defecation. This was due to the ritual impurity of the toilet cabin, we were told, necessitating bathing and changing one's clothing after defecating inside the cabin. Urination took place outside in the family compound or nearby jungle. Family compounds nearly always had a pond, so most members bathed in the pond. For modesty's sake, some women would wash in the cabin itself. As this woman explained her reason for needing a taller, brick and mortar toilet cabin, 'My daughter cannot stand in the cabin and change her clothes now. People passing by will watch. Is this not a problem? She has to come with wet clothes inside the house.' Previous research has noted the ways in which beliefs about impurity/disgust around feces in the South Asian context influenced sanitation behaviors (Srinivas 2002; Drangert & Nawab 2011). Our ethnography brings to light a geographically specific, toilet-using behavior related to ritual impurity beliefs.

Using PLUM data to calculate 'total time in toilet', HP recorded about 32% more movement in a toilet on average than WB. This was consistent with our ethnographic research indicating that HP households use their toilet/bathrooms for other hygiene activities besides defecation. HP respondents did not report that toilet cabins were ritually impure. Instead, IHLs in both HP study sites were often built to take advantage of the single tap in family compounds, serving several purposes: toilet; bathroom; water filling station; and laundry. These larger rooms with easy access to water meant there was more traffic in and out of them, especially by women, for whom gender norms required them to do these tasks.

The differences in mean per capita usage between HP1 and HP2 were also expected. In HP1, 65% of PLUM-accepting households had toilet/bathroom combinations. In HP2, only 23% had toilet/bathroom combinations. When comparing usage events between toilet and toilet/bathrooms across all sites there was a significant difference (P-value 0.00003) indicating that toilet types are important data when using PLUM technology. The difference in per capita toilet use based on toilet type indicated 0.6 fewer uses if the toilet type was 'toilet only' – validating our observations that participants spent less time in these toilet types.

We asked household members in HP1 (our last study site) on the day we removed their PLUM to recall the number of times they defecated the previous day. There was a significant difference between the sensor recorded use average of 2.27 uses per person per day, and the reported use of 1.38 for a Wilcox ranked sum mean difference of 0.85 uses. One sensor monitoring weakness is that it does not detect if the IHL is being used for the deposition of human feces. Ethnography supplied an explanation for the difference: HP1 had more toilet/bathrooms and women reported accessing stored water in the toilet/bathroom space multiple times daily. The photographic record verified that the PLUMs were installed close to toilets, but they were likely capturing non-usage events as well as usage events.

Toilet type

We disaggregated PLUM data based on toilet quality in WB: (1) cement pan in cement slab; or (2) porcelain pan in cement slab using the photographic data set and interview data to determine whether lower cost toilets were used less than higher cost ones. Differences in toilet quality showed no significant difference in per capita usage in WB, where most low cost toilets were located across the four study areas. This result agreed with WB interviews; householders reported that low cost toilets were acceptable and in use. Using Barnard *et al.*'s (2013) criteria for functional latrine (i.e., walls over 1.5 meters; door; unbroken, unblocked pan; and functioning connection to pit (if any)), in WB, latrines were functional, even if those latrines had only plastic sheeting for walls and a door, no roof, and a cement pan. If feces could be flushed, these low cost latrines were used; this was verified by PLUM data. This key finding indicates that basic, low cost models that function are acceptable in communities where toilet use is the social norm.

In WB, a GP had to achieve 90% toilet coverage to win an NGP award. At the time that the NGP toilet drive started in the two study areas, a majority of the households could not afford to build toilets on their own. Availability of low cost cement slabs (250 INR, approximately US$5), free or subsidized pit digging, and walls of plastic sheeting supported widespread, rapid building. In WB2, 50–55% of the households were still using cement pans. In WB1, 40–45% had cement pans or largely subsidized porcelain pans.

There was a clear trajectory of toilet habituation in the region as one elderly man in WB2 explained, 'Earlier people used to go for open defecation OD, then khata paikhana (pit latrine, wooden slab) was built, then plate (pour flush to pit latrine, cement pan) came into existence. Now as people are making money, they are building sanitary paikhana (pour flush to pit latrine, porcelain pan).' As his brief history relates, a significant factor in getting people to stop defecating in the open was enabling them to build pour flush latrines, even those considered temporary, as cement pan latrines were. Plate latrines were a great improvement over pit latrines with wooden slabs or having to practice open defecation. Low cost latrines were less than ideal because they needed periodic reconstruction of toilet cabins, high water tables meant shallow pits (usually 3–4 rings deep) needed to be re-dug, composted, or emptied, but they did not stink, as drop pit toilets did (see also Kvarnstroem *et al.* 2011; Barnard *et al.* 2013). Families in WB that could afford better toilets built with porcelain pans and brick walls built them, but for those who could not, plate latrines were acceptable and were still in use decades after being built.

Pit latrines in HP were larger and had the advantage of well-draining soils and a low water table; few families had ever emptied their pits. Most latrines had porcelain pans with cement slabs, and many families spent disposable income on tanks with piped water supply, decorative tiles, and occasionally, toilet seats.

Peak usage times and occupation

PLUM data verified our ethnographic finding that most household members primarily defecated in the morning (Figure 6). Data also showed a smaller but distinct peak in the evening hours. Sensors do not detect who is using the unit, a problem for per capita usage figures if household numbers fluctuate daily, but the reason households consented to installation. Using ethnography to establish family members' out-of-house routines can narrow the range of individual users throughout the day. For example, men in WB who worked as cycle-cab drivers left their houses early in the mornings and reported defecating elsewhere. Eliminating members of certain occupations as toilet users during peak hours could give more accurate mean per capita usage figures. Information on peak usage times can also assist with: knowing when to station structured observation in future studies verifying toilet usage (e.g., HP peak times were later in the morning than WB peak times (Clasen *et al.* 2012)); capturing off-peak, high usage times (e.g., incidences of diarrhea); and informing shared toilet policy by providing information on peak time, mean per capita per hour figures (i.e., turnover rates).

CONCLUSIONS

A failure to understand sanitation behavior can result in policies that do not meet the needs of target populations. Given high rates of open defecation in India and recently revitalized efforts to end the practice, more research is needed that measures toilet usage and explains the reasons for use and non-use. We purposefully selected unique cases to study successful sanitation uptake, intending our findings to provide new insights, guide further research, and inform interventions. We used ethnography to 'get at' the everyday lived context of study populations' toilet practices by asking people about their values, meanings, and routines. PLUMs counted 'practices', validated interviewees' reporting, and highlighted the significance of specific behaviors.

Our mixed method approach facilitated the general findings that political will, political ecology, and social pressure supported the building and sustained usage of toilets in the study sites (O'Reilly & Louis 2014). Specifically, subsidies were necessary for poor households in WB to build, but these subsidized, low cost toilets were still in use decades after they were built. Contrary to findings that Indians believe latrines are expensive (Coffey *et al.* 2014), or that pit latrines are not sustainable (Kvarnstroem *et al.* 2011), low cost, improved sanitation was used sustainably. We attribute their sustainability to local governments and NGOs in WB that invested in educating families how to manage pit latrines after they filled. As Barnard *et al.* (2013) also found, length of time of ownership mattered for toilet use; users spoke of developing a toilet habit that both supported, and was supported by, social norms in the study areas (see O'Reilly & Louis 2014).

PLUM analysis brought to light our finding that in rural WB toilets were used only for defecation. Due to our immersion in WB, using toilets only for defecating became

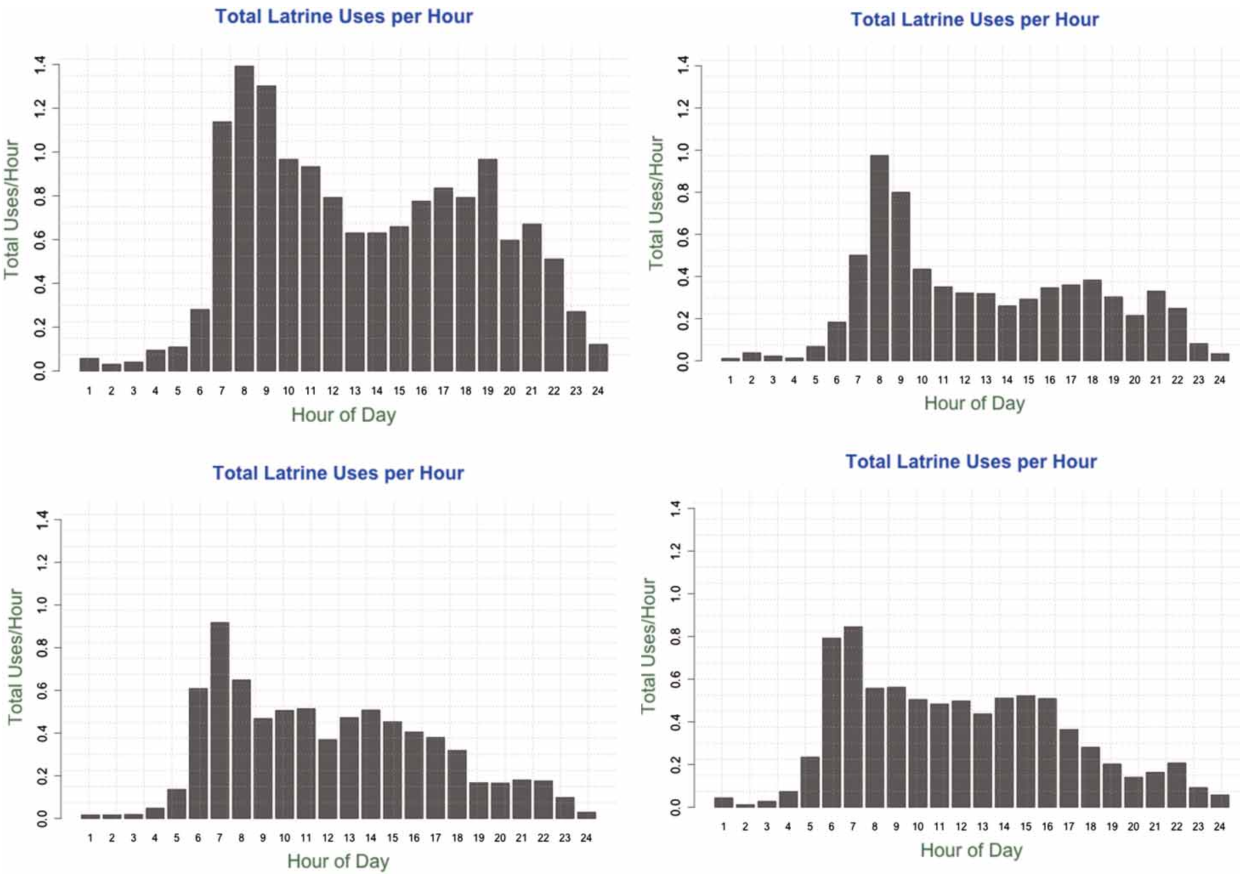

Figure 6 | Time of day usage for all GPs.

normalized. In seeking to explain the differences in mean per capita usage based on PLUM results, we re-discovered WB beliefs of pollution that limited toilet use to defecation. Without the ethnography we could not have explained the PLUM results for WB; without the PLUMs, defecation-only toilet use would have been overlooked. An understanding that a toilet cabin is a polluting space presents new challenges for solving problems such as the disposal of child feces (Jenkins *et al.* 2014) or needing privacy for urination. Currently, PLUMs detect motion in and out of the toilet cabin without information on what occurred inside. Rural WB also presents itself as a place where the PLUM algorithm for usage events might be further refined to assess defecation events since toilets are used only for defecation. Other instruments including audio signal analysis or pressure pads placed near the toilet could also be field tested in WB as further improvement to PLUMs.

As in other studies, we found that not all family members regularly used toilets (Coffey *et al.* 2014; Jenkins *et al.* 2014) but interview data can enable refinement of PLUM data analysis by collecting information on the age and occupation of non-users. This serves the purpose of refining mean per capita usage, and thereby letting us know if the toilet is being used, by how many, and at what time. Standard large-scale survey methods could provide some of the same data (see Barnard *et al.* 2013; Jenkins *et al.* 2014) and be verified by sensor monitoring, but without knowledge of norms and meanings, solutions to problems of non-usage due to occupation and age remain out of reach.

Ethnography relies on trust between the research team and the study community, not just individual interviewees. In small villages in WB and HP occupied by extended families, a misstep could have ended our research at those sites. The question of trust when using combined methodology raises the question as to whether people would be willing to install if they did not live in NGP villages? As stated above, we learned early on that PLUM installations were possible when households were informed that we chose their GP because it was an NGP village – because we knew their toilets were in use. Given the difficulty of installation in places of successful sanitation, installation in locations where populations were informed that they should use toilets but did not, would likely have low PLUM acceptance and could undermine the trust necessary for a rich ethnography.

Ethnography is seldom undertaken as it requires extended field periods and linguistic and cultural fluency, but its strengths lie in discovering new practices, and the surprising, subtle motivations for behaviors. Such discoveries are critical in their own right, but they also can inform other assessment tools. Findings can only be scaled up with caution, because scaling up requires removing norms and meanings from the geographic context where they arose – in this case, tantamount to ignoring the very multi-scalar and intersecting factors (e.g., governance, changing environmental conditions, and processes of social norm development) that produced the conditions of successful sanitation. Similarly, PLUMs are not appropriate for wide-scale measurement of toilet usage in India, given the diversity of behaviors and beliefs across small geographic areas. Nevertheless, the findings from our combined methodology indicate that ethnography and sensor monitoring are important tools in the search for methods to assess toilet usage and behavior.

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APPENDIX 3

Effectiveness of a rural sanitation programme on diarrhoea, soil-transmitted helminth infection, and child malnutrition in Odisha, India: a cluster-randomised trial

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Summary

Background A third of the 2·5 billion people worldwide without access to improved sanitation live in India, as do two-thirds of the 1·1 billion practising open defecation and a quarter of the 1·5 million who die annually from diarrhoeal diseases. We aimed to assess the effectiveness of a rural sanitation intervention, within the context of the Government of India's Total Sanitation Campaign, to prevent diarrhoea, soil-transmitted helminth infection, and child malnutrition.

Methods We did a cluster-randomised controlled trial between May 20, 2010, and Dec 22, 2013, in 100 rural villages in Odisha, India. Households within villages were eligible if they had a child younger than 4 years or a pregnant woman. Villages were randomly assigned (1:1), with a computer-generated sequence, to undergo latrine promotion and construction or to receive no intervention (control). Randomisation was stratified by administrative block to ensure an equal number of intervention and control villages in each block. Masking of participants was not possible because of the nature of the intervention. However, households were not told explicitly that the purpose of enrolment was to study the effect of a trial intervention, and the surveillance team was different from the intervention team. The primary endpoint was 7-day prevalence of reported diarrhoea in children younger than 5 years. We did intention-to-treat and per-protocol analyses. This trial is registered with ClinicalTrials.gov, number NCT01214785.

Findings We randomly assigned 50 villages to the intervention group and 50 villages to the control group. There were 4586 households (24 969 individuals) in intervention villages and 4894 households (25 982 individuals) in control villages. The intervention increased mean village-level latrine coverage from 9% of households to 63%, compared with an increase from 8% to 12% in control villages. Health surveillance data were obtained from 1437 households with children younger than 5 years in the intervention group (1919 children younger than 5 years), and from 1465 households (1916 children younger than 5 years) in the control group. 7-day prevalence of reported diarrhoea in children younger than 5 years was 8·8% in the intervention group and 9·1% in the control group (period prevalence ratio 0·97, 95% CI 0·83–1·12). 162 participants died in the intervention group (11 children younger than 5 years) and 151 died in the control group (13 children younger than 5 years).

Interpretation Increased latrine coverage is generally believed to be effective for reducing exposure to faecal pathogens and preventing disease; however, our results show that this outcome cannot be assumed. As efforts to improve sanitation are being undertaken worldwide, approaches should not only meet international coverage targets, but should also be implemented in a way that achieves uptake, reduces exposure, and delivers genuine health gains.

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See Online for podcast interview with Thomas Clasen

Introduction

An estimated 2·5 billion people have no access to improved sanitation.[1] 71% of these people live in rural areas, as do more than 90% of the 1·1 billion who practise open defecation.[1] Even in areas with moderate sanitation coverage, levels of subnational inequity are high.[2] India represents a particular challenge, accounting for roughly a third of the world's population without improved sanitation and two-thirds of the population practising open defecation.[3] There and elsewhere, governments have supported large-scale campaigns to improve coverage of household sanitation, which is often the sole indicator used to measure progress. Poor sanitation is associated with various infectious diseases, including diarrhoea, soil-transmitted helminth infection, trachoma, and schistosomiasis.[4] Diarrhoea accounts for the largest share of sanitation-related morbidity and mortality, causing an estimated 1·4 million deaths annually,[5] including 19% of all deaths of children younger than 5 years in low-income settings.[6] Furthermore, evidence has linked poor sanitation with stunting, environmental enteropathy, and impaired cognitive development—long-term disorders that aggravate poverty and slow economic development.[7]

Although historical efforts to improve sanitation were voted by readers of the *British Medical Journal* as the most important medical advance since 1840,[8] evidence of the health effect of household sanitation in low-income settings is not strong. Investigators of systematic reviews report that improved sanitation can reduce the prevalence of diarrhoeal diseases by 22–36%.[9–12] However, the studies included in these reviews were observational or small-scale trials and of poor methodological quality; most combined household sanitation with water supplies or hygiene. Investigators of recent systematic reviews reported household sanitation to be protective against soil-transmitted helminth infection and trachoma; however, these had the same shortcomings as previous reviews.[13–15] Another review[16] identified no intervention studies of the effect of household sanitation on child anthropometry, although ecological analyses have linked open defecation with stunting in India[17] and other low-income countries.[18]

We did this study to assess the effectiveness of a rural household sanitation intervention to prevent diarrhoea, soil-transmitted helminth infection, and child malnutrition. We aimed to investigate the effect of the intervention as actually delivered by an international implementer and its local partners working in India within the context of the Total Sanitation Campaign—the largest sanitation initiative in the world so far.[19]

Methods

Study design and participants

We did this cluster-randomised controlled trial between May 20, 2010, and Dec 22, 2013, in 100 rural villages in Puri, a coastal district of Odisha (formerly Orissa), India. Trial design, setting, and characteristics of the study population have previously been described.[20] Briefly, included villages were spread across seven of the 11 blocks (an administrative subdistrict) of the Puri District. Agriculture is the main source of income in Odisha and half of households are classified as living below the poverty line, according to the Government of India.[21] India ranks among the lowest of states nationally in terms of access to household-level latrines, with 14·1% coverage in rural settings.[22] Furthermore, Puri District is not covered by any regular deworming programme.

We selected study villages from a list of 385 villages that had not been covered by the Total Sanitation Campaign. Villages were eligible if they had sanitation coverage of less than 10%; had improved water supply; and if no other water, sanitation, or hygiene (WASH) intervention was anticipated in the next 30 months. Households were eligible if they had a child younger than 4 years or if a pregnant woman lived there. We also enrolled households with a new baby born during the surveillance phase. We did a baseline survey between September and October, 2010, to obtain information about household demographic characteristics; socioeconomic status; water, hygiene, and sanitation conditions; and diarrhoea prevalence.

The study was reviewed and approved by the ethics committee of the London School of Hygiene & Tropical Medicine (London, UK), and by Xavier University and Kalinga Institute of Medical Sciences, KIIT University (both in Bhubaneswar, India). Written informed consent was obtained from the male or female head of household before baseline data collection.

Randomisation and masking

A member of staff who was involved in neither data collection nor intervention delivery randomly assigned villages (1:1), with a computer-generated sequence, to undergo either latrine promotion and construction in accordance with the Total Sanitation Campaign or to receive no intervention (control). Randomisation was stratified by administrative block to ensure an equal number of intervention and control villages in each block. Randomisation achieved a good balance of socioeconomic and water and sanitation-related characteristics.[20] Masking of participants was not possible because of the nature of the intervention. However, households were not told explicitly that the purpose of enrolment was to study the effect of a trial intervention, and the surveillance team was different from the intervention team.

Procedures

The intervention consisted of latrine promotion and construction, in accordance with the Government of India's Total Sanitation Campaign, which combines social mobilisation with a post-hoc subsidy. Implementation was coordinated by WaterAid India (part of WaterAid, an international non-governmental organisation [NGO] working in sanitation) and United Artists Association (an Odisha-based NGO). Six local NGOs were contracted to deliver the intervention in intervention villages in collaboration with local government. Implementation was undertaken between January, 2011, and January, 2012. The Government of India provided subsidies (INR 2200 [US$44] in January, 2011) for the construction of latrines that met specified criteria in below-poverty-line households. The latrine design consisted of a pour-flush latrine with a single pit and Y-joint for a future second pit. Each participating below-poverty-line household was to be provided with a latrine and households contributed sand, bricks, and labour. The subsidy did not cover the cost of full walls, door, and roof. A detailed assessment of the implementation process has been reported elsewhere.[23]

We measured compliance with the intervention with a survey done at the midpoint of the follow-up period. The survey recorded latrine presence and functionality, reported latrine use, and global positioning system (GPS) location of latrines and households. We defined latrine functionality on the basis of the following elements: existence of a roof; latrine not used for storage; pan not broken, not blocked, and not full of leaves or dust; and pit completed. We confirmed present latrine use on the basis of several indicators: smell of faeces, wet pan except when rainy, stain from faeces or urine, presence of soap, presence of water bucket or can, presence of a broom or brush for cleaning, or presence of slippers.

We measured the effect of the intervention on environmental exposure to faecal pathogens through typical transmission pathways by testing for the presence of faecal indicator bacteria in source and household drinking water, on children's and mothers' hands and on children's toys, and by monitoring fly density. 20% of participating households were randomly selected at each visit for testing of source and household microbial drinking water quality. Samples were collected from sources and storage vessels with sterile 125 mL Whirl-Pak bags (Nasco Ft, Atkinson, WI, USA), transported in a cooler to the laboratory, and processed within 4 h of collection with the membrane filtration technique and a portable incubator, in accordance with standard methods.[24] Samples were tested for thermotolerant coliforms—an indicator of faecal contamination.[25] To assess hand contamination, we obtained hand rinse samples[26] from mothers and children younger than 5 years from a subsample of 360 households (about six households from 30 intervention and 30 control villages) and assayed them for thermotolerant coliforms. Furthermore, we provided sterile balls to children younger than 5 years from the same 360 households, encouraged them to play with the toys in their household settings for 1 day, rinsed them in 300 mL of sterile water, and assayed the water for thermotolerant coliforms.[27] Finally, we monitored density of synanthropic flies (*Musca domestica* and *M sorbens)* by installing 24 h fly traps for 3 consecutive nights in food preparation areas of a subsample of 572 households from 32 intervention and 32 control villages.

Household visits were done every 3 months between June, 2011, and October, 2013. Because of delays in latrine construction resulting in the target coverage not being met until January, 2012, the first three rounds of diarrhoea surveys after the baseline survey were not included in the primary analysis, resulting in a total of seven rounds of data collection.

We measured prevalence of three common soil-transmitted helminth worms—*Ascaris lumbricoides, Trichuris trichiura,* and hookworm spp—by collecting stool samples from study participants aged 5–40 years (living in households with a child younger than 5 years). Baseline measurement was done in June and July, 2011, with subsequent sampling done after the last follow-up round. On the same day of collection, samples were transported to the laboratory and processed with the ethyl-acetate sedimentation method,[28] and eggs were quantified with microscopy. After baseline stool collection, one 400 mg dose of albendazole (200 mg for children), a broad-spectrum anthelmintic, was given to individuals enrolled for stool sampling (except women in their first trimester of pregnancy), in accordance with WHO recommendations.

A baseline measure of weight (in children younger than 5 years) and recumbent length or height (in those younger than 2 years) was taken in January, 2012. The same children, and those born during the study, were measured again in October, 2013. Weight was measured with Seca 385 scales, with 20 g increments for weight lower than 20 kg and increments of 50 g for weight between 20 kg and 50 kg. We measured recumbent length of children younger than 2 years with Seca 417 boards with 1 mm increments. We measured height of children aged 2 years and older with a Seca 213 stadiometer. Back-checks on weight and height measurements were done in roughly 5% of households selected at random.[29]

Statistical analyses

The primary outcome was 7-day prevalence of reported diarrhoea in children younger than 5 years. 7-day prevalence was recorded for all household members on the basis of reports from the primary caregiver.[30,31] We defined diarrhoea with the WHO definition of three or more loose stools in 24 h.[32] In secondary analyses, we stratified the primary analysis by age, household size, population density (defined as the number of people living within 50 m, on the basis of GPS survey) and below-poverty-line status.

The sample size was based on the proportion of days with diarrhoea (longitudinal prevalence) of children younger than 5 years. We assumed a mean longitudinal

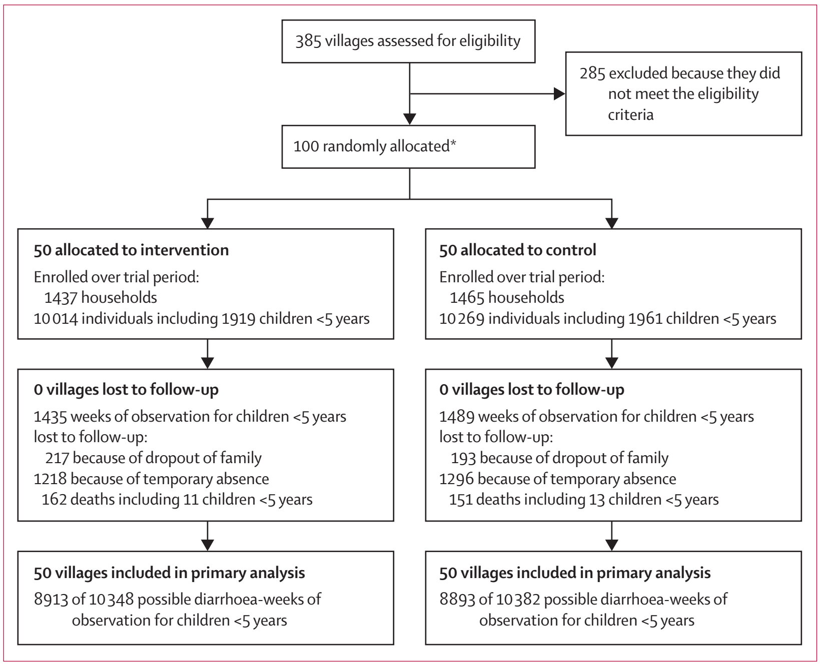

Figure 1: **Trial profile**
*Across seven blocks.

	Intervention villages	Control villages	Percentage point difference (95% CI)
Baseline			
Households with any latrine*	9% (8, 0–32)	8% (6, 0–27)	+1% (–2 to 4)
Post-intervention			
Households with any latrine	63% (18, 15–90)	12% (11, 0–47)	+51% (45 to 57)
Households with functional latrine	38% (17, 8–80)	10% (9, 0–37)	+28% (23 to 34)
Households with functional latrine and signs of present use	36% (16, 7–76)	9% (8, 0–37)	+27% (22 to 32)
Households with functional latrines by number of people in household			
<5	32% (16, 15–71)	6% (7, 0 to 26)	+25% (20–30)
5–8	41% (19, 6–82)	12% (11, 0 to 47)	+29% (23–35)
>9	51% (29, 0–100)	19% (22, 0 to 100)	+32% (22–42)
Households with functional latrines by BPL status*			
BPL card	47% (26, 0–100)	10% (18, 0 to 100)	+37% (28–46)
No BPL card	40% (21, 0–77)	17% (22, 0 to 100)	+23% (15–32)
People with access to functional latrine	46% (18, 6–81)	15% (12, 0–48)	+30% (24 to 37)

Data are mean proportion (SD, range). Values calculated from village-level data, based on 4585 intervention and 4895 control households surveyed at study midpoint. BPL=below poverty line. *Calculated with status data from baseline survey (973 intervention and 1001 control households with children <5 years).

Table 1: **Latrine coverage at village level at baseline and post-intervention**

	Denominator		Median bacterial colony or fly count		Effect size (95% CI)
	Intervention	Control	Intervention	Control	
Water quality					
Household water	2406*	2505*	60	60	1·06‡ (0·89–1·24)
Source water	1951*	1918*	1	1	1·08‡ (0·90–1·30)
Hand contamination					
Mothers	175†	177†	205·8	469	0·88‡ (0·49–1·58)
Children <5 years	172†	167†	107	107	0·85‡ (0·47–1·55)
Sentinel toy	164†	162†	1·5	3	0·83‡ (0·50–1·40)
Total synanthropic flies	288*	284*	12	13	0·73§ (0·46–1·16)

*Number of households. †Number of individuals. ‡Odds ratio from ordered logistic regression (categories 0, 1–10, 11–100, 101–1000, 1001–10 000, more than 10 000 colony forming unit per 100 mL of water, two hands, or toy). 95% CI adjusted for clustering by use of robust SEs, proportionality of odds tested with likelihood ratio test (all p>0·3). §Rate ratio from negative binomial regression (counts aggregated at village level).

Table 2: **Effect of intervention on water quality, hand contamination, and flies (intention-to-treat analysis)**

daily prevalence of 4% (SD 7·6) in this population, with the assumption of six follow-up visits per child.[30] We assumed a 25% reduction in diarrhoea prevalence as a figure of public health interest and in line with estimates from systematic reviews.[9–12] With an assumed 25 children per cluster, an intracluster correlation of 0·025, a design effect of 1·6, and 10% loss to follow-up, 80% power and a p value of 0·05 resulted in 50 clusters per study group. This figure was confirmed with a simulation method developed for the sample-size estimation of complex trials.[33]

We calculated prevalence ratios of diarrhoea and soil-transmitted helminth infection in intervention and control villages with log-binomial models (binomial distribution, log-link). Village-level clustering was accounted for by generalised estimating equations with robust SEs. We converted height and weight into height-for-age and weight-for-age Z scores[34] and calculated mean differences in these scores with random-effects linear regression, adjusted for baseline values and accounting for village-level clustering. Negative binomial regression was used to calculate rate ratios of count data (soil-transmitted helminth eggs and flies), by aggregation of counts at village level, and with use of the number of samples in a village as exposure. Due to zero inflation and right truncation of bacterial counts of thermotolerant coliforms assays, we grouped these counts into log categories (0, 1–10, 11–100, etc, per 100 mL) and compared them between intervention and control groups with ordered logistic regression (with robust SEs to account for village-level clustering), which calculates the odds ratio of being in a higher category. Because only 33% of follow-up stool samples were from individuals who had also given a baseline sample, the analysis of worm infection focused on follow-up samples.

In addition to the primary intention-to-treat analysis, we did a per-protocol analysis for village-level and household-level compliance for all health outcomes. For this purpose, a village was defined as compliant if 50% or more households had a functional latrine at the midpoint of follow-up. Households were defined as compliant with the protocol if they had a functional latrine at midpoint (intervention group) or not (control). To reduce the potential for bias inherent in per-protocol analyses, we adjusted for baseline diarrhoea. No per-protocol analysis was done for soil-transmitted helminth infection, as only a few baseline samples could be matched to follow-up samples, and baseline samples from five villages (four from the control group) were lost, making adjustments for baseline values unreliable. We did analyses with STATA (version 10).

This trial is registered with ClinicalTrials.gov, number NCT01214785.

Role of the funding source

The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

Figure 1 shows the trial profile. We randomly assigned 50 villages to the intervention group and 50 villages to the control group. There were 4586 households (24 969 individuals) in intervention villages and 4894 households (25 982 individuals) in control villages; 1437 households from the intervention group and 1465 households from the control group met the eligibilty criteria and were enrolled for health surveillance (figure 1). For diarrhoea surveillance, 10 014 individuals, including

1919 younger than 5 years were enrolled in the intervention at some point during surveillance, as were 10 269 individuals (n=1961 younger than 5 years) in the control group. Baseline and follow-up weight-for-age *Z*-score measures were available for 1462 individuals (n=650 younger than 2 years) in the intervention group and 1490 individuals (n=637 younger than 2 years) in the control group. Baseline and follow-up height-for-age *Z*-score measures were available for 350 individuals (71% of children measured at baseline) in the intervention group and 337 (74%) children in the control group. The proportion of worm samples obtained at baseline was similar in the intervention and control groups (1521 [44%] of 3457 *vs* 1438 [43%] of 3344), and worm samples at follow-up were obtained from 2231 (52%) of 4255 in the intervention group and 2063 (47%) of 4379 in the control group.

In the intervention villages, the mean proportion of households with a latrine increased from 9% at baseline to 63% at follow-up (table 1). At follow-up, 11 of 50 intervention villages had functional latrine coverage of 50% or greater, and seven had coverage of less than 20%. In the control villages, mean household-level coverage increased from 8% at baseline to 12% at follow-up (table 1). At follow-up, two of 50 control villages had coverage with functional latrines greater than 30% (none had coverage of 50% or greater), and 41 had coverage of less than 20%. Because households with more individuals were more likely to have a functional latrine, the total proportion of the people with access to a functional latrine was higher than the household-level coverage (table 1). 1729 (63%) of 2732 households with any latrine in the intervention group reported that household members were using the latrine; of these, 1690 (98%) of 1724 reported that women were using it, 1364 (79%) of 1725 reported that men were using it, and 903 (79%) of 1140 households with children reported that children were using it.

The intervention had no effect on overall faecal contamination of water stored in the households of study participants (table 2). No evidence showed that latrine construction affected contamination of wells. We recorded a trend for reduced contamination of the hands of mothers and children younger than 5 years in the intervention group (12% and 15% reduction, respectively, in the odds of being in a higher category of contamination), and on the sentinel toy (17% reduction of odds), compared with participants in the control group; however, this finding was not significant (table 2). Similarly, there were numerically, but not significantly, fewer synanthropic flies in the intervention group than in the control group (table 2).

Reported 7-day diarrhoea prevalence in children younger than 5 years was 8·8% in the intervention group and 9·1% in the control group (figure 2), with a decline in late 2012, corresponding to the cold and dry season. No evidence showed that the intervention was protective against diarrhoea in children younger than 5 years, or against diarrhoea in all age groups (table 3). No effect of the intervention was detected when the population was stratified by household size, population density, or below-poverty-line status (table 3). The per-protocol

Figure 2: **7-day prevalence of diarrhoea in children younger than 5 years (solid lines) and individuals aged 5 years and older (dashed lines) over seven rounds of follow-up, by intervention status**

	Denominator (individuals)		Diarrhoea prevalence*		Prevalence ratio (95% CI)
	Intervention	Control	Intervention	Control	
Intention-to-treat analysis					
By age					
Children <5 years	1919	1961	8·8%	9·1%	0·97 (0·83–1·12)
All ages	10 014	10 269	3·8%	3·7%	1·02 (0·88–1·18)
By household size†					
0–4 members	388	441	8·3%	8·3%	0·98 (0·74–1·30)
5–8 members	917	942	8·6%	10·0%	0·90 (0·76–1·07)
>9 members	614	578	9·2%	7·8%	1·09 (0·88–1·36)
By BPL status†					
Has BPL card	561	626	8·4%	8·7%	0·95 (0·77–1·18)
No BPL card	777	757	8·9%	7·8%	1·10 (0·90–1·36)
By population density (residents of all ages within 50 m radius)†					
0–100	637	655	9·3%	8·1%	1·07 (0·86–1·33)
101–200	669	611	9·7%	10·0%	0·93 (0·72–1·20)
>200	456	554	8·4%	8·8%	0·95 (0·76–1·18)
Per-protocol analysis†					
Villages with functional latrine coverage ≥50%					
Crude	299	1409	8·6%	9·1%	0·92 (0·75–1·15)
Adjusted‡	299	1409	..	..	0·98 (0·78–1·24)
Households with functional latrine					
Crude	612	1211	7·5%	8·6%	0·90 (0·74–1·08)
Adjusted‡	612	1211	..	..	0·95 (0·79–1·13)

Table shows results from log-binomial models, clustering by village accounted for by use of generalised estimating equations. BPL=below poverty line. *Crude mean village-level prevalence of diarrhoea. †Children younger than 5 years. ‡Adjusted for baseline village-level prevalence of diarrhoea and baseline individual diarrhoea prevalence (calculated combining diarrhoea data from the baseline survey and the first two rounds that were done before October, 2011).

Table 3: **Effect of the intervention on diarrhoea prevalence**

	Denominator (individuals)		Mean Z-score, STH prevalence, or mean STH egg count		Effect size (95% CI)
	Intervention	Control	Intervention	Control	
STH infection					
Intention-to-treat analysis					
STH prevalence	2231	2063	16·0%	16·4%	0·97* (0·72 to 1·32)
STH egg counts per g	2151	2002	10·2	9·4	1·08† (0·62 to 1·88)
Hookworm prevalence	2231	2063	14·1%	15·6%	0·90* (0·66 to 1·22)
Hookworm egg counts per g	2151	2002	8·7	9·1	0·96† (0·54 to 1·68)
Prevalence of *Ascaris lumbricoides*	2229	2063	0·7%	0·3%	2·04* (0·38 to 10·91)
A lumbricoides egg counts per g	2150	2000	0·9	0·5	1·85† (0·07 to 48·75)
Prevalence of *Trichuris trichiura*	2229	2063	2·6%	0·6%	3·89* (1·38 to 10·92)
T trichiura egg counts per g	2149	2002	0·9	0·1	9·90† (1·98 to 46·62)
Weight-for-age Z score‡					
Intention-to-treat analysis					
Children <5 years at baseline	1462	1490	–1·48	–1·43	0·02§ (–0·04 to 0·08)
Children <2 years at baseline	650	637	–1·46	–1·32	–0·01§ (–0·12 to 0·09)
Per-protocol analysis (children <5 years at baseline)					
Villages with functional latrine coverage ≥50%	324	1490	–1·36	–1·43	0·10§ (0·003 to 0·20)
Households with functional latrine	683	1274	–1·32	–1·50	0·12§ (0·05 to 0·20)
Height-for-age Z score‡					
Intention-to-treat analysis	350	337	-1·56	–1·36	–0·10§ (–0·22–0·02)
Per-protocol analysis					
Villages with functional latrine coverage ≥50%	75	337	–1·45	–1·37	–0·04§ (–0·24 to 0·16)
Households with functional latrine	161	294	–1·42	–1·39	–0·06§ (–0·27 to 0·15)

STH=soil-transmitted helminth. *Log-binomial models, clustering by village accounted for by use of generalised estimating equations. †Random-effects linear regression. ‡We excluded children with *Z* scores greater than 5 or of 5 and lower. §Negative binomial regression of sum of village-level egg counts with number of samples in village as exposure.

Table 4: **Effect of intervention on anthropometric measures and worm infection**

analysis did not suggest an effect of the intervention on diarrhoea in children younger than 5 years, neither from village-level coverage nor from presence of a functional latrine in an individual household (table 3). The baseline mean village-level prevalence of diarrhoea was highly correlated with follow-up village-level prevalence (r^2 0·79 in children younger than 5 years).

The baseline total worm prevalence was similar between the groups (17·6% *vs* 17·0%). No evidence showed that the intervention reduced prevalence or egg counts of all soil-transmitted helminth infections, or of *A lumbricoides, T trichiura,* or hookworm (table 4). At follow-up, 576 (87%) of 662 prevalent soil-transmitted helminth infections were due to hookworm and 6963 (84%) of 8288 identified eggs were hookworm eggs.

The intervention had no effect on mean weight-for-age *Z* score in children younger than 5 years, or in those younger than 2 years, at baseline (table 4). Findings from the per-protocol analysis suggest evidence for an increase in weight-for-age *Z* score in compliant villages and households (table 4). The primary analysis showed no effect on mean height-for-age *Z* score in children younger than 2 years at baseline, and the per-protocol analysis suggested no major effects (table 4).

162 participants died in the intervention group (11 children younger than 5 years) and 151 died in the control group (13 children younger than 5 years). The intracluster correlation coefficient for diarrhoea due to village-level clustering of diarrhoea (with exclusion of correlation due to repeated measurements) was 0·02 for children younger than 5 years and 0·01 for all age groups. The coefficients for weight-for-age and height-for-age *Z* score at follow-up were both 0·06. The coefficients for combined prevalence of soil-transmitted helminth infection was 0·09.

Discussion

Our findings show no evidence that this sanitation programme in rural Odisha reduced exposure to faecal contamination or prevented diarrhoea, soil-transmitted helminth infection, or child malnutrition. These results are in contrast with systematic reviews that have reported significant health gains from rural household sanitation interventions (panel).[9–15] However, they are consistent with another trial of a sanitation project implemented within the context of the Total Sanitation Campaign in the Indian state of Madhya Pradesh.[35]

Insufficient coverage and use of latrines seem to be the most likely causes for the absence of effect, because no evidence showed that the intervention reduced faecal exposure. Although mean coverage of latrines increased substantially in the intervention villages, more than a third of village households (on average) remained without a latrine after the intervention. About twice that many had no functional latrine that was used at the midpoint of the surveillance period. Latrine functionality is an objective measure of some use by the household; however, it cannot discern use by individual householders. Other evidence exists to show suboptimum use of latrines constructed as part of the Total Sanitation Campaign, particularly by men and children,[36,37] and for the disposal of child faeces.[38] Although we detected no effect of the intervention at coverage of 50% or higher with functional latrines, that level of coverage and inconsistent use still represents high levels of continued open defecation and thus a substantial opportunity for continued exposure to faecal pathogens at the village level. Another possible explanation for our negative findings is that improvements in household sanitation alone are insufficient to mitigate exposure to faecal–oral pathogens. Hands can be contaminated by anal cleansing of oneself or a child that is not followed by handwashing with soap, and food can be contaminated during production or preparation. Animal faeces could also be contributing to the disease burden—a possibility that we

Panel: Research in context

Systematic review

Before undertaking this trial, we did a systematic review of interventions to improve disposal of human excreta for prevention of diarrhoea.[11] We searched the Cochrane Infectious Disease Group Specialized Register; the Cochrane Central Register of Controlled Trials, published in The Cochrane Library; Medline; Embase; Lilacs; the metaRegister of Controlled Trials; and Chinese-language databases available under the Wan-Fang portal, the China National Knowledge Infrastructure. We aimed to identify randomised and quasi-randomised controlled trials comparing interventions for improvement of the disposal of human excreta to reduce direct or indirect human contact with no such intervention. Search terms, other search strategies, eligibility criteria, and other methods are described in the published review. 13 studies from six countries covering more than 33 400 children and adults in rural, urban, and school settings met the review's inclusion criteria. While the studies reported a wide range of effects, 11 of the 13 studies showed that the intervention was protective against diarrhoea. Almost all previous studies combined the sanitation with improvements in water supply, hygiene, or both; as such identification of the contribution of sanitation alone was not possible. Differences in study populations and settings, in baseline sanitation levels, water and hygiene practices, types of interventions, study methods, compliance and coverage levels, and case definitions and outcome surveillance restricted the comparability of results of the studies and rendered a meta-analysis inappropriate. The validity of most individual study results were further compromised by the non-random allocation of the intervention among study clusters, an insufficient number of clusters, scarcity of adjustment for clustering, unclear loss to follow-up, potential for reporting bias, and other methodological shortcomings. Our review provided some evidence that interventions to improve excreta disposal are effective for prevention of diarrhoeal disease. However, this conclusion is based mainly on the consistency of the evidence of beneficial effects. The quality of the evidence is generally poor and does not allow for quantification of any such effect. Rigorous studies in various settings are needed to clarify the potential effectiveness of excreta disposal on diarrhoea. Other systematic reviews have shown sanitation interventions to be protective against diarrhoea.[9–10,12]

Interpretation

Our findings raise questions about the health effect of sanitation initiatives that focus on increasing latrine construction but do not end open defecation or mitigate other possible sources of exposure. Although latrine coverage increased substantially in the study villages to levels targeted by the underlying campaign, many households did not build latrines and others were not functional at follow-up. Even householders with access to latrines did not always use them. Combined with other possible exposures, such as no hand washing with soap or safe disposal of child faeces, suboptimum coverage and use may have vitiated the potential health effect generally reported from improved sanitation. These results are consistent with those from another trial.[35] Although the sanitation campaign in India has been modified to address some of these challenges, the programme still focuses mainly on the building of latrines—the main metric for showing progress towards sanitation targets. Although these efforts should continue, sanitation strategies can optimise health gains by ensuring full latrine coverage and use, ending open defecation, and minimising other sources of exposure.

are exploring in our substudy of microbial source tracking.[20] Exposure to rotavirus or zoonotic agents such as *Cryptosporidium* spp, both of which have been reported to be a major cause of severe to moderate diarrhoea in India, might only be partly prevented by sanitation.[39] Another explanation could be that the latrines themselves were ineffective at containing excreta; however, no evidence showed that latrines contaminated water sources. Additionally, the 14-month construction period and 18-month surveillance period might not be long enough to eliminate the risk of pre-intervention faeces in the environment. Some soil-transmitted helminth eggs and protozoan cysts can persist for extended periods outside a host, and some enteropathogenic bacteria can multiply in suitable environments.[40]

All these possible explanations are important areas for further research. For now, however, increasing of village-level coverage and use would seem to be a priority. The levels achieved in our study are not unusual under the Total Sanitation Campaign and thus cannot be dismissed as an aberration.[36,37,41] From 2001 to 2011, only two of 509 districts in India increased latrine coverage by more than 50%.[22] Changes to the Total Sanitation Campaign (which has been renamed the Nirmal Bharat Abhiyan) increase and extend subsidies for construction beyond households below the poverty line to specified vulnerable groups.[19] However, most households above the poverty line still do not qualify for subsidies and must build their own latrines. Although the Total Sanitation Campaign includes incentives through the Nirmal Gram Puraskar scheme to encourage village-wide open-defecation-free status, most villages do not qualify. Other approaches to rural sanitation, including community-led total sanitation, emphasise 100% latrine coverage in each village.

An important limitation of our study relates to the 18-month follow-up period. The potential health effect of rural sanitation (especially with regard to slow-reacting outcomes such as worm infection and stunting) might not be measurable within this time. This drawback raises questions about the feasibility of sanitation trials, especially because a more successful programme (eg, using sanitation marketing and enhanced community mobilisation) might take 5–10 years to be implemented in areas with a low initial demand—a period during which investigators would encounter difficulties in withholding an intervention from a control group.[42]

Although we recorded no evidence for bias caused by self-reported or carer-reported diarrhoea data, this possibility is a further limitation.[31] The per-protocol analyses were adjusted for baseline values, but residual confounding is possible. Even with the potential for residual confounding, the per-protocol analysis showed no consistent effects in villages or households with higher compliance, except for weight-for-age *Z* score, which was not consistent with the absence of effect on height-for-age score. Compliance with the intervention might be related not only to child weight-for-age *Z* score at baseline, but also independently to the rate of decline in weight-for-age score in the first 2 years of life, which we noted in our study area.

Household sanitation could provide other benefits, including convenience, dignity, privacy, and safety. Latrine use was nearly five times higher for women than for men or children. However, our results show that the health benefits generally associated with sanitation cannot be assumed simply by construction of latrines. As efforts to expand sanitation coverage are undertaken worldwide, approaches need to not only meet coverage-driven targets, but also achieve levels of uptake that could reduce levels of exposure, thereby offering the potential for genuine and enduring health gains.

Contributors

TC, SB, MB, OC, JE, MF, MJ, AS, and W-PS contributed to the study design. SB, PR and BT managed the study. SB led the substudy of water quality, MO and MJ the substudy of hand contamination, BT the substudy of sentinel toys, and MB the substudy of flies. WS and AS coordinated the assessment of latrine coverage and use. WS was responsible for the analysis of health outcomes. TC, SB, and WS drafted the report. All authors contributed to redrafting the report.

Declaration of interests

We have no competing interests.

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Impact of Indian Total Sanitation Campaign on Latrine Coverage and Use: A Cross-Sectional Study in Orissa Three Years following Programme Implementation

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Abstract

Background: Faced with a massive shortfall in meeting sanitation targets, some governments have implemented campaigns that use subsidies focused on latrine construction to overcome income constraints and rapidly expand coverage. In settings like rural India where open defecation is common, this may result in sub-optimal compliance (use), thereby continuing to leave the population exposed to human excreta.

Methods: We conducted a cross-sectional study to investigate latrine coverage and use among 20 villages (447 households, 1933 individuals) in Orissa, India where the Government of India's Total Sanitation Campaign had been implemented at least three years previously. We defined coverage as the proportion of households that had a latrine; for use we identified the proportion of households with at least one reported user and among those, the extent of reported use by each member of the household.

Results: Mean latrine coverage among the villages was 72% (compared to <10% in comparable villages in the same district where the Total Sanitation Campaign had not yet been implemented), though three of the villages had less than 50% coverage. Among these households with latrines, more than a third (39%) were not being used by any member of the household. Well over a third (37%) of the members of households with latrines reported never defecating in their latrines. Less than half (47%) of the members of such households reported using their latrines at all times for defecation. Combined with the 28% of households that did not have latrines, it appears that most defecation events in these communities are still practiced in the open.

Conclusion: A large-scale campaign to implement sanitation has achieved substantial gains in latrine coverage in this population. Nevertheless, gaps in coverage and widespread continuation of open defecation will result in continued exposure to human excreta, reducing the potential for health gains.

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Background

An estimated 2.5 billion people lack access to improved facilities for the disposal of human excreta, such as a basic pit latrine [1]. Globally 1.1 billion people, including an estimated 638 million in India alone, still practice open defecation [1]. Seven out of ten people who are without improved sanitation live in rural areas. Projections make clear that current progress will fall short of meeting the MDG sanitation target to halve the portion of the population without access to improved sanitation by 2015 [1].

Faced with this challenge, governments, non-governmental organizations (NGOs) and others have undertaken large-scale efforts to expand sanitation coverage. The most ambitious of these is the Governments of India's Total Sanitation Campaign (TSC), recently revised and renamed the Nirmal Bharat Abhiyan, which was first implemented in 1999 [2]. The TSC is a low-subsidy regime that aims to generate household involvement and demand responsiveness for the building of individual household latrines in below poverty line (BPL) households [3]. It also uses information, education and communication strategy in rural areas designed to generate demand, elicit greater community involvement and encourage use of latrines [4].

The TSC has been largely effective in increasing latrine coverage. According to Government of India records, almost 90 million individual household latrines have been built as a result of the campaign [5]. In addition to the subsidies, the TSC operates a scheme called the Nirmal Gram Puraskar that provides community incentives to Gram Panchayats (local governments) for achieving full open defecation free status [6]. Recent changes under the Nirmal Bharat Abhiyan reforms extend the subsidies beyond BPL households to specified groups. However, most households that are above the poverty line do not qualify for subsidies and must build their own latrines. Perhaps as a result, latrine coverage in villages usually falls well short of 100% [6,7].

While work continues on achieving sanitation coverage, programme implementers also face the challenge of securing their use by householders. Achieving consistent and widespread use is a common problem for top-down, subsidy-driven sanitation campaigns. It is one impetus for community-led total sanitation, an approach that emphasizes the adverse impact of any non-compliance and uses community-wide mobilization and behaviour change strategies in lieu of subsidies in an effort to achieve lasting open defecation free status [8]. However, securing such compliance is a particular challenge in rural India where open defecation is the norm; two-thirds of the estimated 1.1 billion people who practice open defecation worldwide reside in India [1]. Unlike improved water supplies that are readily embraced in rural settings, achieving latrine use within a population requires changes in private behaviours based on deeply held cultural practices [9]. In a recent assessment of a 5-year water, sanitation and hygiene promotion programme in the southern Indian state of Tamil Nadu, investigators reported a substantial increase in latrine coverage, from 15% to 48%; however, even among households that had built a latrine, 39% of adults and 52% of children were reported to continue the practice of open defecation [10].

Achieving both coverage and use, however, are essential in order to realise the health benefits associated with improved sanitation. Even a comparatively small number of non-users can contaminate the environment with faecal pathogens, causing direct exposure to faecal pathogens through contact and indirect exposure via mechanical vectors (flies) and contaminated drinking water [7,11]. Microbiological evidence and modeling based on quantitative microbial risk assessment suggests that high levels of coverage and use are necessary to minimize exposure and prevent disease [12–14].

Our research group is undertaking a cluster randomized, controlled trial to assess the impact of the TSC as implemented by Water Aid and its NGO partners in a costal district in Orissa (Odisha), a state in Eastern India where open defecation is still widespread and faecal-oral diseases are common [15]. While the study will document the impact of the intervention on latrine coverage and use, it will only follow the population for 21 months following a 12-month implementation period. In order to explore the impact of such an intervention over a longer period, we undertook this cross-sectional study in non-study villages in the same district where the TSC was implemented at least three years previously.

Methods

Study area and village selection

The study was conducted in June and July 2012 among 20 villages in Puri District, a rural region located on the coast of the East Indian state of Orissa. Villages were eligible for inclusion in the study if the TSC was undertaken by an implementing partner NGO of WaterAid India at least three years prior to the study. Participating villages were selected randomly from a list of 35 eligible villages provided by implementing partners of WaterAid India.

Household selection and enrollment

All households in the selected villages were eligible for inclusion in the study. Sampled households were selected randomly following a sampling strategy used for the Extended Program on Immunization (EPI) [16]. A pen was spun in a central location in the village to determine the direction in which the enumerator would sample households. Every second household was sampled until the enumerator reached their quota of households or until they reached the boundary of the village. If the boundary was reached prior to meeting the quota, the enumerator returned to the central location repeat the process. Three enumerators were asked to sample at least seven households per villages, though the aggregate number depended in part on logistics. Households were enrolled if they consented to participate after receiving complete details of the study. Non-consenting households or households where no adult was present at the time of the visit by an enumerator were replaced by the next household on the list.

Survey tool and procedure

The main study tools consisted of surveys and spot checks of latrines by trained enumerators using Oriya, the local language. Separate surveys for households with and without access to latrines were developed, translated, piloted and back-translated to confirm accuracy. Each survey included questions on basic demographics, size of household, whether the household had a BPL card, type of household construction, religion, highest level of education of female and male heads of household, and distance to nearest water source. They were also asked about exposure to sanitation promotion messages as part of the TSC implementation. Surveys were conducted with the consenting female head of household, or in her absence, a male or female over 18 years.

Assessing coverage and use

Household latrine coverage was assessed using the question "does your household have a latrine?" Those that answered affirmatively were classified as having a latrine. In households with a latrine, enumerators visually examined the latrine and assessed its functionality [17–18]. Latrines were considered "functional" if they met the following criteria: walls over 1.5 meters, some type of closure over the entry for privacy, an unbroken and unblocked toilet pan and a functional pan-pipe-pit connection. Households that had a latrine were asked if the latrine was used by any member of the household. Those that responded affirmatively were further asked to report the age, gender and place of defecation of each member of the household.

Data Entry and Analysis

Data was entered using EPIData 3.1 and analysed using STATA 12. Bivariate analysis of associations between risk factors and outcome variables was conducted using chi square tests. Logistic regression was then performed to examine the strength of association between covariates with a p value <0.05. To investigate the association between the covariates and latrine coverage and the association between the covariates and latrine use, multivariable models were built using a hierarchical conceptual framework [19–20]. To avoid an excess number of variables and unstable estimates in the subsequent model, only variables with a p-value of <0.10 were kept in the subsequent model analysis [20]. In order to adjust for clustering within villages, generalized estimating equations with robust standard errors were used in multivariate analysis.

Ethics

The study was approved by the ethics committees of the London School of Hygiene and Tropical Medicine and Xavier Institute of Management Bhubaneswar. Surveys and observations were undertaken only after obtaining informed written consent using a prescribed information sheet. No compensation was paid to study participants. In order to ensure anonymity, no names were recorded during data collection and the analysis was done using household codes.

Results

Sampled Population

Table 1 provides information on the 20 villages included in the study, including year of TSC implementation. Villages were located within 5 different blocks in the Puri district. Four NGOs had implemented the TSC in the study villages 3 to 8 years prior to our study (mean 5.3 years).

A total of 447 households were sampled from these 20 villages, representing a mean of 22.5 households sampled per village (range = 18 to 26). This yielded data on 1933 individuals who lived in households that had a latrine. The median number of people per household was 5 (95% CI 5,6) with a range from 1 to 30 people per household (data not shown). The majority of households (68%) either presented a BPL card or claimed to have one. Most (79%) households had heard of a program promoting latrine construction, though fewer (31%) had heard of Village Water and Sanitation Committee (VWSC) members or (20%) had heard of VWSC meetings.

Latrine coverage and characteristics

Latrine coverage among villages ranged from 38% to 95%, with a median of 75% and a mean of 72% (95% CI = 64,80) (Table 1). In Orei, a village certified as open defecation free, coverage was 90%.

Of the 321 latrines in the study villages, 150 (47%) met the functionality criteria (walls over 1.5 meters, some type of closure over the entry, an unbroken and unblocked pan and a functional pan-pipe-pit connection) (Table 2). More than half (65%) were built with TSC subsidy of cash or materials and most (88%) were pour flush latrines. Few of the latrines sampled had a broken or blocked pan (11%) or non-functional pan-pipe-pit connection (7%), though many (44%) lacked a closure over the entry for privacy.

In multivariable analysis, the variables that were significantly ($p = <0.05$) associated with having a latrine were: type of household construction, having heard of a latrine promotion program and having heard of VWSC members (Table 3). Households made of Pucca (concrete) had almost 4 times the odds of having a latrine than Kucha (mud and dung) households (aOR = 3.57 95% CI = 2.25,5.65, $p = <0.001$). Households who had heard of a program promoting latrine construction (aOR = 2.07 95% CI = 1.17,3.66, $p = 0.012$) and those who were aware of VWSC members (aOR = 2.07 95% CI = 1.03,4.15, $p = 0.04$) had more than double the odds of having a latrine than those who had not.

Latrine use

Of the 126 households (28%) that did not have a latrine, informants reported that all members of the household practice

Table 1. Village, year of implementation, implementing partner, coverage and use.

Village	Year of TSC Implementation	No. Households Sampled	% Latrine Coverage	% Reported Latrine Use for households and individuals with a latrine	
				Households*	Individuals**
Banakhandi	2007–08	25	64	69	56
Banilo	2007–08	21	95	70	50
Bagalei	2008–2009	26	58	63	47
Begunia	2006–07	25	72	58	43
Nagapur golapur	2006–07	27	48	86	65
Dahangaria	2006	20	55	82	56
Orei***	2006–07	21	90	63	61
Bhanapur	2005	21	86	44	36
Hantapada sasana	2004	22	68	67	59
Panidola	2007	20	60	67	46
Ganeswarpur	2006–07	22	95	90	72
Hatasahi	2006	22	86	74	56
Bantalsingh deuli	2007	22	86	74	69
Swainkera	2007	21	90	47	33
Paridobandha	2007	22	86	26	11
Mathasahi	2007	24	58	13	10
Goudasahi	2007	23	78	56	28
Pradhansahi	2007	18	44	0	0
Baliapatana	2007	24	38	75	21
Tandikera	2008	21	86	89	76
Total/Mean		**447**	**72**	**61**	**47**

*Percentage of households that reported at least one member used the latrine sometimes.
**Percentage of household members that were reported to be using the latrine all of the time.
***Awarded Nirmal Gram Puraskar and open defecation free status.
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Table 2. Latrine Characteristics.

Covariate	Number (%)
Number of households with latrines	321 (72)
Received cash or materials from NGO for building of latrine	209 (65)
When the latrine was built	
Less than 3 years ago	81 (25)
3 to 10 years ago	166 (52)
More than 10 years ago	68 (23)
Type of latrine	
Pour flush pit latrine	282 (88)
Direct drop pit latrine	19 (6)
Other	20 (6)
Height of latrine walls	
Below 1.5 meters	114 (36)
Over 1.5meters	205 (64)
Any type of closure over entry for privacy	
No	142 (44)
Yes	178 (56)
Any type of roof	
No	153 (52)
Yes	143 (48)
Pan condition	
Broken/Blocked/Choked	32 (11)
Not broken	265 (89)
Pan-pit pipe connection	
Not connected	20 (7)
Connected and functional	285 (93)
Number of pits	
One	269 (87)
Two	41 (13)
Pit covering	
Pit open or mainly open	12 (4)
Pit visible and fully covered or buried	299 (96)
Size of pit	
Fewer than 3 rings	15 (5)
3 rings or more	190 (64)
Tank (no rings)	91 (32)
Number of times pit has been emptied	
Never	286 (91)
Once or more	29 (9)
*Latrine functional**	
No	171 (53)
Yes	150 (47)

*Walls over 1.5 meters, some type of closure over the entry, unbroken and unblocked pan and a functional pan-pipe-pit connection.
NGO Non-Governmental Organizations.
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open defecation. Among the 321 households (72%) that had latrines, 62% reported that at least one member of the household was using the latrine (Table 1). However, less than half (47%) of the individuals at these households reported using them all of the time (Table 4). Of these, 54% were females. Even among these households with latrines, 37% of householders were reported to always practice open defecation. Another 5% reported always defecating in the compound; these were mainly young children (Table 4). The remaining individuals were reported to either use the latrine "sometimes" or "usually" (usually was defined as more often than not) (Table 4).

The most common reasons why latrines were not in use was that individuals within households preferred open defecation (29%), the latrine was not complete (28%) or using a latrine was deemed inconvenient (20%). Other reasons for non-use were that the latrines lacked privacy (23%), were used for storage (22%), were broken (17%) or blocked (9%). Only one household ascribed non-use to water being too distant, and only 4% of households reported that it was too difficult to empty the pit.

In the multivariable analysis of latrine use, households that had built their latrines over 10 years ago had more than 4 times the odds of using their latrine (aOR = 4.59 95%CI = 1.82,11.60, p = 0.001) (Table 5). Latrines with walls over 1.5 meters (aOR = 10.21 95% CI = 4.01,26.00, p = <0.001), those with a pan that is not broken (aOR = 8.89 95% CI = 2.56,30.84, p = 0.001) and those with a fully covered pit (aOR = 43.74 95% CI = 4.44,430.70, p = 0.001) were also more likely to be in use. Latrines with any type of closure over the entry (door) were much more likely to be in use (aOR = 42.98 95% CI = 18.13,101.92, p = <0.001) (Table 5). All of the households with a pan pipe-pit connection that did not function were not using their latrine. Latrines which had walls over 1.5 meters, a closure over the entry, an unbroken and unblocked pan and a functioning pan-pipe-pit connection (functional latrines) were more likely to be used than non-functional latrines (aOR = 25.59 95%CI = 12.07,54.26, p = <0.001).

Perceived benefits of latrine use

When asked what the benefits of latrine use were, 66% suggested that there were health benefits associated with latrine use, 39% believed that latrines provided safety and security for women or girls and 27% felt they provided privacy (Figure 1). Of those reporting that there is no open space for defecation, 77% either did not have a latrine or were not using their latrine. No associations were found between the perceived benefits of having a latrine and latrine use.

Discussion

We undertook a cross-sectional study to assess latrine coverage and use in 20 villages where the TSC had been implemented at least three years previously. If high levels of both coverage and use are necessary to minimize exposure and optimize health impact, our results show deficiencies in both areas.

While the evidence suggests that the campaign was effective in increasing coverage, there were shortcomings. Almost half of the villages achieved at least 80% coverage. While there is no pre-intervention data from these villages, baseline data from a large trial in 100 villages in the same district showed pre-intervention coverage of 8.2% [15]. Given that the TSC extends only to BPLs and limited classes of other priority groups, this suggests that the campaign was effective in significantly increasing latrine coverage among this population. However, coverage was not universal, even in the village with open defecation free status. Moreover, 9 of the 20 villages sampled achieved less than 70% coverage, with 3 reaching less than 50%. This wide variation is consistent with findings from previous studies and demonstrates a need for more consistent implementation of the TSC [6,7,21]. There are also issues about the quality or longer-term robustness of the latrines;

Table 3. Multivariable regression analysis of factors associated with latrine coverage.

Coverage Multivariable Analysis				
Covariates	**Household with latrine**	**Adj OR**	**95% CI**	**P value (Wald)**
Household construction				
Kucha	58	1		
Semi-Pucca	67	1.71	1.08,2.73	0.023
Pucca	80	3.57	2.25,5.65	<0.001
Heard of a program promoting latrines				
No	57	1		
Yes	75	2.07	1.17,3.66	0.012
Heard of VWSC members				
No	66	1		
Yes	85	2.07	1.03,4.15	0.040

Denominators vary as not all respondents answered all questions.
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only 47% met basic criteria established for functionality. Finally, despite targeting the campaign to BPL households, coverage was associated with more costly home construction (pucca rather than kucha); there was also some evidence of an association between latrine construction and secondary education of the female head of household.

Securing consistent use of the latrines represents an even greater challenge. Of the 72% of households sampled that had latrines, more than a third (39%) were not being used by any member of the household. This figure is lower than that reported in similar studies [17,22,23] but higher than the 48% reported from Tamil Nadu [10]. Less than half (47%) of householders with access to their own latrines reported always using them for defecation. Consistent with previous research, more women used latrines exclusively than men though the difference (females 54% and males 46%) was not as large as has been seen elsewhere [24]. Well over a third of the members of such households reported never defecating in the latrines; another 8% reported using them only occasionally. Combined with the 28% of households that did not have latrines, it is clear that most defecation events in these communities are still practiced in the open and not in a latrine.

These results suggest that the TSC has not succeeded in substantially reducing exposure to human excreta in these villages. Under these circumstances, it is not clear whether the TSC would be capable of achieving health gains in these communities [7,11]. Even if only a few members of the community are defecating in the open, the risks to health remain substantially high [12,14,25].

Table 4. Reported place of defecation for individuals in households where there is a latrine *N = 1933.*

Place of defecation	Number (%)
Always use a latrine	904 (47)
Usually use a latrine	49 (30)
Sometimes use a latrine	150 (8)
Always open defecation	723 (37)
Always open defecation within the compound	106 (5)

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This may be particularly true if the refractory members of the community are more likely to be "super shedders" or if safe disposal of child faeces is poor, an important source of exposure [26].

However, the actual impact of sanitation on human health is complex, and the level of coverage and use that is necessary to prevent disease is not well understood [21]. A recent working paper that carefully and comprehensively analyzes datasets on TSC implementation and child health has found the campaign to be associated with significant reductions in child mortality and child stunting [7]. While such study designs are susceptible to unknown confounders and offer more limited potential for causal inference, it is possible that even sub-optimal levels of coverage and use can deliver favorable health outcomes.

The most common reason reported for not using a latrine was that people prefer open defecation. Open defecation is a cultural practice that is deeply engrained in communities in India [27–28]. In a study conducted in rural southern India, respondents reported that open defecation did not carry stigma and was hygienically preferable to using a latrine, since they were not accumulating faeces near the house [29]. While the TSC includes social mobilisation and information, education and communication activities that are aimed at overcoming the cultural practice of open defecation within communities [28,30], our results suggest that this aspect of the campaign may be sub-optimal. If so, this may be a structural deficiency in the TSC, as campaign implementers are compensated for building latrines (coverage) and not for securing their use. New technologies that discretely and objectively monitor latrine use [31] could be incorporated into the TSC in order to compensate programme implementers for securing sustained use. Restructuring the campaign to focus on longer-term use may also address some of the deficiencies in quality and sustainability of construction.

In June 2012, the Government of India revised the TSC and renamed it as Nirmal Bharat Abhiyan. Among other things, the revisions seek to secure 100% coverage in communities. The major revisions of the programme are (i) an increased focus on administration at the Gram Panchayat level, (ii) expansion to include above poverty line households as well as below poverty line households, (iii) an increase in the subsidy with greater flexibility on the latrine type, (iv) inclusion of the schools, and (iv) additional

Table 5. Multivariable regression analysis of factors associated with latrine use.

Use Multivariable Analysis				
Covariates	**Household reporting latrine use**	**Adj OR**	**95% CI**	**P value (Wald)**
When was the latrine built				
Less than 3 years ago	48	1		
3 to 10 years ago	60	2.54	1.07,6.04	0.034
More than 10 years ago	90	4.59	1.82,11.60	0.001
Height of latrine walls				
Below 1.5 meters	30	1		
Over 1.5meters	81	10.21	4.01,26.00	<0.001
*Any type of closure over entry for privacy ** *				
No	23	1		
Yes	94	42.98	18.13,101.92	<0.001
Pan condition				
Broken/Blocked/Choked	13	1		
Not broken	74	8.89	2.56,30.84	0.001
Pit covering				
Pit open or mainly open	8	1		
Pit visible and fully covered or buried	66	43.74	4.44,430.70	0.001
*Latrine Functional****				
No	33	1		
Yes	95	25.59	12.07,54.26	<0.001

Denominators vary as not all respondents answered all questions. Use is based on reported use.
**Closure over entry and roof assessed in a model which excluded walls because no latrines without walls had a roof or door.
***A functional latrine is defined as a latrine which has walls over 1.5 meters, some type of closure over the entry, an unbroken and unblocked pan and a connected and functional pan-pipe-pit connection.
aORs for functional latrines assessed in a model which included village, household construction, pit covering and length of time since latrine has been built.
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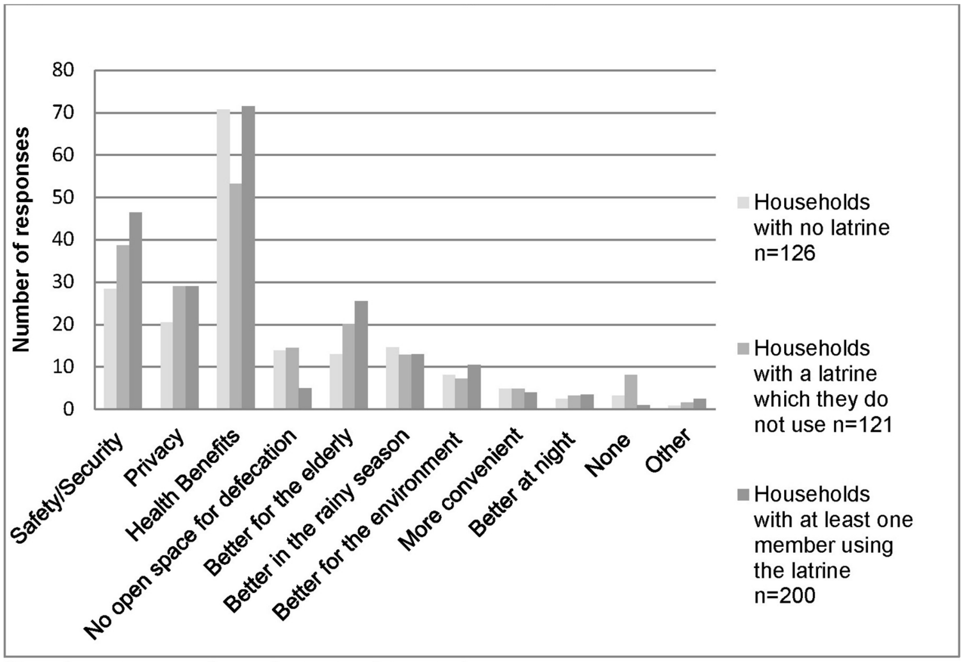
management of the waste stream [2]. This shift in focus was inspired by the reported success of the Nirmal Gram Puraskar aspect of the TSC which provided monetary incentives to achieving open defecation free villages and promoted 100% latrine coverage in rural areas [6]. Our study included one village that had previously been awarded Nirmal Gram Puraskar status. Although coverage was relatively high (90%) in this village, use of latrines was well below optimal at 63%. It is not clear whether the revisions to the programme will be more successful in optimizing latrine use.

However, another reason for low use may be that the latrines are of poor quality. Of the 321 latrines that we sampled, only 150 (47%) met the criteria for functionality, including minimal wall height and a door or other closure to ensure privacy. This is lower than what has been reported in other studies [17,23]. Functional latrines were much more likely to be used; sufficient wall height, roofs, functional pans, buried or covered pits and doors or other closures to ensure privacy were all associated with higher levels of use. Overall, 95% of 'functional' latrines were in use, compared to only 33% of those that were not considered as 'functional'. On the other hand, latrines that householders wish to use are also more likely to be better constructed and maintained, and lack of latrine use may lead to lack of latrine functionality. The recent revisions to the campaign do not clearly address these construction deficiencies. While the increased subsidies and greater design flexibility may yield higher quality latrines, they may also attract more opportunistic implementers to the sector.

This study has several important limitations. First, like any cross-sectional design, the study offers few insights into temporal relationships between the TSC and latrine ownership and use. Second, the selection of villages included in the study was not random and the results cannot be generalized beyond the 20 villages included in the study. Though the villages were randomly selected from a list provided by the implementing organization, we cannot rule out the potential for selection bias. Third, the EPI sampling strategy has certain limitations [16], and the absence of village census data prevented us from using population proportional sampling or other methods that may have helped ensure the accuracy of our estimates of coverage and use within each community. Fourth, it is also possible that because the study was carried out in rainy season, use of latrines was higher than at other times in the year. There is also the potential for courtesy bias in self-reporting of latrine use [31] however; it is likely that both of these factors would exaggerate the actual level of use, rendering our estimates conservative. Future studies should attempt to use a range of methods to measure use, possibly including instrumented monitoring [31]. Finally, this study provides no evidence of the extent to which various levels of latrine coverage or use impact exposure to faecal pathogens or health outcomes such as diarrhoea, intestinal nematode infection, or stunting. These will be addressed in the trial that is due to be completed in late 2013 15].



*Denominators vary as not all respondents answered every question
**Multiple responses were permitted

Figure 1. Benefits of latrine use according to respondents. Regardless of whether a household had a latrine, or whether it was in use, the most commonly reported benefit of latrine use was health benefits, followed by safety and security. Households that had a latrine that was in use were less likely to be aware of whether there was no open space for defecation. Few households reported that using latrines were more convenient or better at night.
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Author Contributions

Conceived and designed the experiments: S. Barnard PR FM RP S Boisson AS TC. Performed the experiments: S. Barnard PR FM. Analyzed the data: S. Barnard S. Boisson TC. Contributed reagents/materials/analysis tools: S. Barnard PR FM S. Boisson AS. Wrote the paper: S. Barnard PR FM RP S. Boisson AS TC.

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APPENDIX 5

Instruction Manual – PLUM v3

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Operation

PLUM is composed of two components:

1) A main board, based on the EPIC platform, that performs data collection, storage, and transmission. The EPIC platform is an open hardware wireless sensor networking platform that was developed at UC Berkeley for application – driven embedded system design.[i]
2) A secondary sensor board that houses the PIR sensor used for sensing motion

Detection Mechanism

PLUM uses a PIR (Passive InfraRed) sensor to detect the presence of a heat source. Passive infrared sensing detects the infrared radiation emitted by the human subject.

A PIR sensor is an electronic device that measures infrared (IR) light radiating from objects in its field of view. The term passive in this instance means that the PIR device does not emit an infrared beam but merely passively accepts incoming infrared radiation. "infrared" ("below red") because red represents the lowest energy level in the visible spectrum of human eyes. Thus, infrared means below the energy level of the color red, and applies to many sources of invisible energy.[ii]

The main board runs an embedded operating system called TinyOS that is designed for low-power wireless devices, such as those used in sensor networks, ubiquitous computing, personal area networks, smart buildings, and smart meters.[iii]
The PLUM sensor checks for motion every 5 seconds. Every time motion is detected, the embedded application timestamps and stores this as an event on its local flash storage for later retrieval. In addition to the timestamp, other information including the battery voltage is stored.

Communication Mechanism

Each node transmits regular updates about its status, at the rate of once every two minutes. These status updates include data about the device including its ID, battery status, and remaining flash storage space. These updates can be received by any paired "mote" device plugged into the USB port of a netbook computer running the PLUM software. The "TelosB mote" device is able to communicate with the PLUM nodes by listening for status updates and initiating data downloads from the node to the computer. This data, formatted as a .CSV file (comma-separated value file), will be stored in the local file system in the PLUM "DropBox" folder in the data subfolder.
DropBox offers a cloud-based file storage mechanism that automatically duplicates the entire PLUM data repository on all of the machines on which the repository is shared via the Internet. Thus, when the netbook computer is connected to the Internet, it will

automatically sync the PLUM data repository with all of the computers that have access to it.[iv]

Enclosure Design:

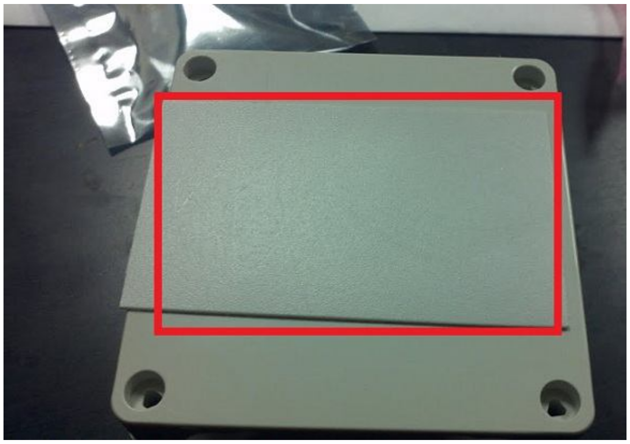
The PLUM is designed to be a waterproof device, with an IP67 rating. It has a rocker switch on the top of the enclosure for turning the device's power ON and OFF. The enclosure has a lid that is connected via four screws, which need to be tight to ensure waterproofness. The lid is on the bottom of the enclosure and exposes the PIR sensor.

Pictures are shown below

BOTTOM VIEW WITHOUT LID

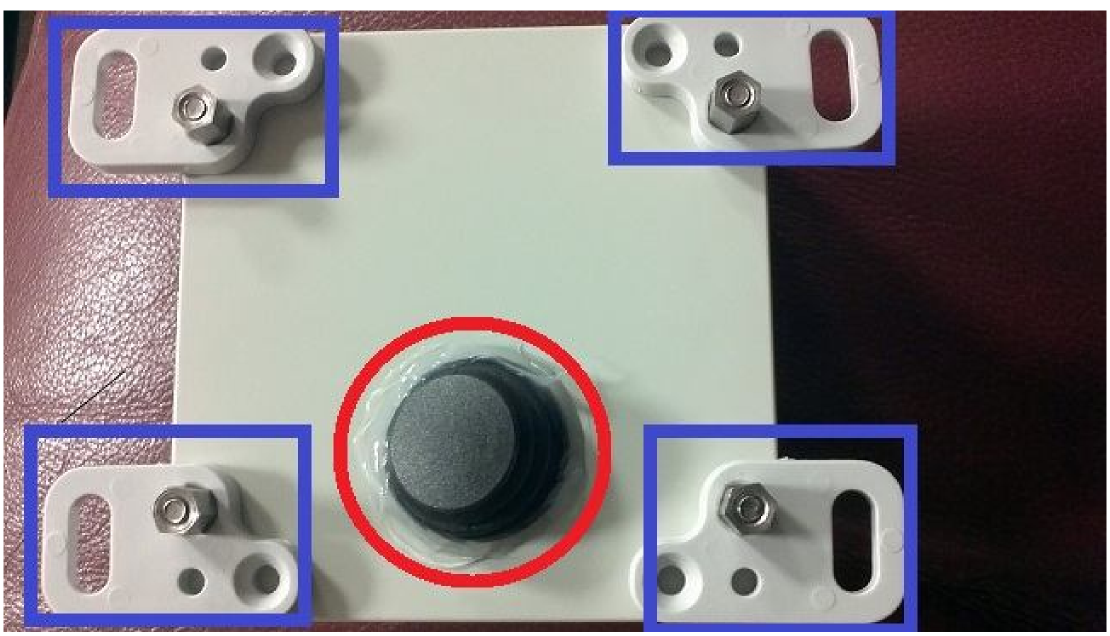
a) Yellow outline shows the main board
b) The blue outline shows the secondary sensor board
c) The red outline shows the PIR sensor (covered with a domed "Fresnel" lens for protection and optical filtering)

BOTTOM VIEW WITH THE LID



a) The red rectangle shows the white screen below which the sensor is placed.
b) The four screws that attach the lid to the enclosure can be seen in each of the four corners. These will need to be detached in order to access the inner compartment and change the batteries.

TOP VIEW



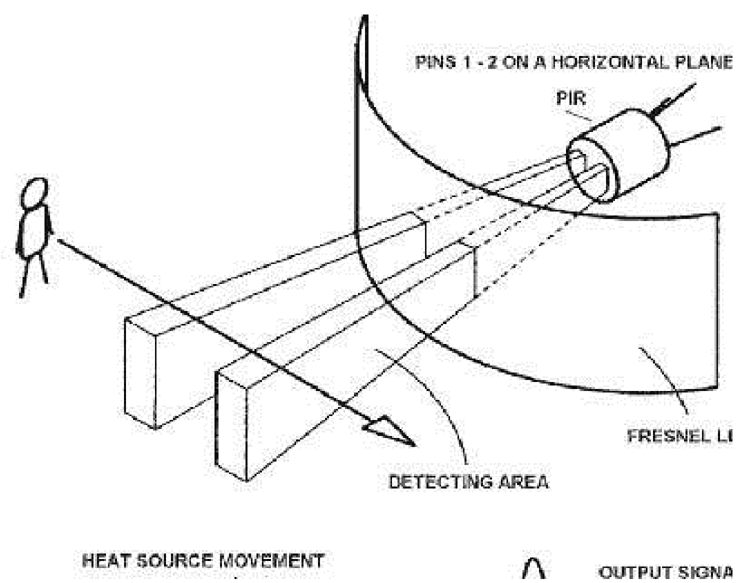
a) The red circle highlights the power switch for turning the node ON and OFF. There is a label on the side of each device indicating which direction is ON and which is OFF.

b) The blue rectangles show the four "feet" that can be used for mounting the PLUM.

Installation:

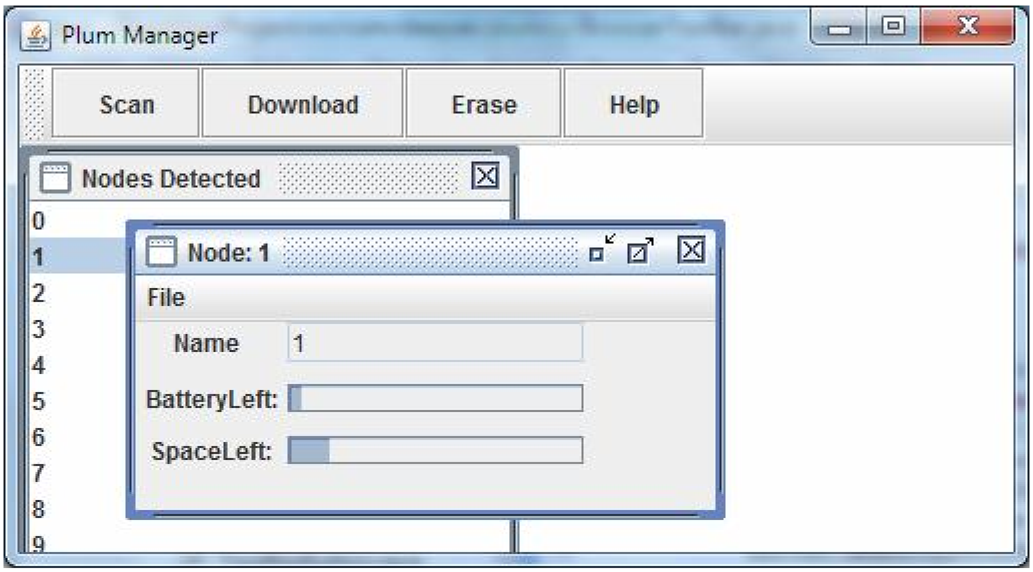
1) Ensure the power switch is in the ON state according to the label on the side of the node.
2) Install the node in the latrine so that the bottom of the box (with the lid) faces towards the latrine.
3) Ensure that the top of the node (with the power switch) is hidden from the latrine users to discourage tampering.
4) Ensure that the screen is facing away from the entrance so that it does not detect false positives by some one who is moving around the entrance.

The figure below shows the detection zone of the PIR sensor.[v] As can be seen, it is critical that that the device is oriented facing the heat source in order to detect motion. Otherwise, no motion will be detected and no useful data will be produced.



PLUM Software:

To collect data from a PLUM node, connect a "TelosB more" to a netbook via USB and run the PLUM software.



The user has the following options:

1) Scan – Scan for PLUM nodes in the vicinity of the data collector (radio range is approximately 10 meters, but varies based on attenuation from barriers). This operation must be performed first so that the software can communicate with the devices found nearby. This process can take up to two minutes to detect all of the PLUM nodes in the area.
2) Download – Read the data from a PLUM node to the netbook. The user will need to select the device from the list populated by the scan operation. This process can also take up to two minutes per device.
3) Erase – Erase the data from a PLUM node – provide the ID of the PLUM node that will be erased. Do this only after verifying that the desired data has been collected. This process can take up to two minutes to complete.
4) Help – Software help

You can look at the status of any node by clicking on that node in the "Nodes Detected" window

Replacing the Battery:

1) Switch off the device
2) Unscrew the four screws that attach the lid to the bottom of the enclosure using a Philips-head screw driver. If using an automatic screwdriver, be careful to not strip the screws.
3) Lift the protruding portion of the secondary board (as seen on the right of the first picture in this document) slightly to allow the battery holder to come loose.
4) Remove the battery holder from the node. Note that the holder is still attached to the main board, so be careful in removing it from the enclosure. Pulling it too hard will damage the PLUM node and will require repair.
5) Remove the batteries and replace them with new batteries. Alkaline or Nickel-Metal Hydrive (NiMH) AA cells both work. Ensure the polarity of the batteries is correct before inserting them.
6) Slightly lift/bend the protruding portion of the secondary board in order to wedge the battery holder against the inside wall of the enclosure. The sensor board should rest against the battery holder to keep the battery holder in place. This should allow clearance for the lid of the enclosure to shut.
7) Put the lid back on the enclosure and screw the four screws until they are tight. That will ensure waterproofness. If using an automatic screwdriver, be careful to not strip the screws.

Operating conditions

Waterproofing

The device is designed to be waterproof (IP67) allowing it to be exposed to extensive water splashing from all sides. However, it cannot be submerged in water.

PIR Sensor range

The PIR sensor can detect motion within a range of about 15 feet (4.57 m).

Battery Specifications:

Two AA batteries that can provide 3000 mAh capacity at 1.2-1.5 V. [These are the specifications of the original batteries in the PLUM node]. Lower capacity batteries will reduce the lifetime of the device.

Operating temperature range:

0 to 50C

Wireless Communication range**:**

Approximately 10 meters (Variable based on environment and surroundings)

Flash Storage capacity

2 MB

References

[i] http://www.cs.berkeley.edu/~prabal/projects/epic/
[ii] http://en.wikipedia.org/wiki/Passive_infrared_sensor
[iii] http://www.tinyos.net/
[iv] http://www.dropbox.com/
[v] http://www.ladyada.net/learn/sensors/pir.html